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Abstract

The issues related to traffic management in cases of disasters have been inadequately addressed in many disaster management plans and real-time processes. This phenomenon results in ineffective disaster management which is crucial to several lives and properties. The current disaster management plans and policies reveal an incomplete understanding of the role and clear contribution of the traffic management in fulfilling the disaster management processes. Disaster management tends to be ineffective without its integration into traffic management. Such considerations have led to the initiation of this study which provides traffic management integration-framework, traffic management operational-framework, traffic management measures and workable strategies in cases of disasters.

This dissertation thesis is initiated by developing a practical understanding of state-of-the-art of disaster management plans and processes. The traditional and contemporary disaster management approaches are studied. The academic and planning publications indicate that disaster management plans are not correctly practiced and they focus mainly on post-disaster management. The common deficiencies in the planning processes and the organisational structure of disaster management in India and Germany are reviewed.

After developing the understanding of state-of-the-art disaster management, the state-of-the-art traffic management plans and process are then reviewed especially for their use in disaster management. The reviews on traffic management assist the formulation of goals and objectives, and the establishment of possible stakeholders, mechanisms, processes and strategies. The relationships between the disaster management and traffic management are established according to main four phases of disaster management. The development of the integration framework is crucial to the development of the transport sector for the disaster mitigation, disaster preparedness, disaster response and disaster recovery. The integration framework is expected as an indispensible aid to transport policy makers for disaster traffic management.

The next endeavour presents the overview of traffic and transport problems in disasters. The traffic and transport issues and problems are evaluated based on the possible disaster impacts on transport infrastructure, transport modes, and transport users. The issues and problems related to both disaster management and traffic management are identified based upon case-study cities, Nagapattinam and New Delhi. The prevailing boundary conditions of case-study cities provide motivation to develop the operational framework of traffic management in cases of disasters. The operational framework defines vision statement, mission statements, goals, and objectives of traffic management in cases of disasters. This framework significantly contributes to developing orientation of traffic managers to manage transport situation in disasters.

An important part of this dissertation thesis is the development of 27 traffic management measures which are segregated into eight public transport measures, two non-motorised transport measures, four individual motorised transport measures, ten multi-modal and inter-modal transport measures, and three freight transport measures. The qualitative model of measure assessment is developed to evaluate the effectiveness and the applicability of 27 measures in the disaster situations. The measures are then grouped into six priority classes based on their effectiveness and applicability scores. The inferences of the assessment suggest that improvement of the applicability of measure is obtained by reducing the difficulties of implementation. Therefore, applicability improvement measures are suggested for traffic management measures which are very effective and at the same time difficult to implement. These applicability improvement measures are intended to improve the rating of measures and thus include in the formation of traffic management strategies.

Nine traffic management strategies are formulated to influence both the traffic demand and transport supply in disaster-affected or prone areas. The development of strategies considers the prior qualitative assessment of traffic management measures. In the development of TM strategies, the possible measures are identified and suggested after carefully considering compatibility between measures that form a strategy. In the course of this dissertation, the relationships between TM measures, TM modules and TM strategies are established.

This dissertation thesis includes the use of principles of scenario planning to qualitatively assess the transport situations in cases of disasters. Such assessment provides the decision-making help to traffic managers on the appropriate activation of strategies, requirement of traffic management modules and traffic management measures. The transport situation is assessed based largely upon three factors: the disaster impacts on transport supply and demand, transport development state of the disaster area and the transport operation performance during disasters. Those criteria and indicators are identified which can be used to assess the transport situation in disasters. Also, the interrelationships between different factors governing transport situation assessment are determined. A disaster transport situation assessment model is developed to predict the situation level determined through the cumulative scores obtained from situation rating (rating of situation factors) and their relative weights of importance.

The proposals of application of TM modules are given for the case study city-New Delhi. The proposals confined to pre-identified traffic management mechanisms and processes (TM modules) for the city of New Delhi. The examples of possible traffic management measures in cases of disasters in New Delhi are also summarised. The main facts, observations, and conclusions derived from the dissertation study are explained chapter-wise. Also the technical difficulties witnessed during the dissertation process are explained and the resulting limitations of study are stated. Finally the recommendations for further research in the area of ‘traffic management in cases of disasters’ are made.

Zusammenfassung

In vielen Katastrophenplänen und bei der Umsetzung dieser Pläne im realen Katastrophenfall werden Aspekte des Verkehrsmanagements nicht adäquat berücksichtigt, was auf ein unvollständiges Verständnis der Rolle und des Beitrags des Verkehrsmanagements bei der Bewältigung der Katastrophen zurückzuführen ist. Daraus folgt ein ineffektives Katastrophenmanagement, das für Leben und Eigentum der Betroffenen gefährlich werden kann. Solche Überlegungen waren Ausgangspunkt der vorliegenden Arbeit, die die Rahmenbedingungen für die Integration des Verkehrsmanagements in das Katastrophenmanagement und für die operative Umsetzung des Verkehrsmanagements im Katastrophenfall erarbeitet. Desweiteren werden Maßnahmen und Strategien hierfür entwickelt.

Am Anfang dieser Dissertation wird ein praktisches Verständnis der derzeitigen Katastrophenpläne und -prozesse entwickelt, indem sowohl traditionelle als auch die gegenwärtigen Ansätze untersucht werden. Die einschlägigen wissenschaftlichen und technischen Veröffentlichungen zeigen, dass Katastrophenpläne nicht immer korrekt umgesetzt werden und sich zudem hauptsächlich auf die Zeit nach der Katastrophe beziehen. Diese Arbeit stellt grundsätzliche Verbesserungspotenziale in den Planungsprozessen und den Organisationsstrukturen Indiens und Deutschlands dar.

Danach werden die derzeitigen Verkehrsmanagementpläne und -prozesse speziell im Hinblick auf ihre Anwendung im Katastrophenfall untersucht. Es werden Ziele und Zwecke formuliert sowie festgelegt, wer möglicherweise betroffen ist und welche Mechanismen, Prozesse und Strategien notwendig sind. Die Verknüpfungen zwischen Katastrophen- und Verkehrsmanagement werden entsprechend den vier Phasen des Katastrophenmanagements dargestellt. Die Entwicklung der Rahmenbedingungen für die Integration des Verkehrsmanagements in das Katastrophenmanagment ist entscheidend für die Beiträge des Verkehrsbereiches zur Minderung der Katastrophenauswirkungen, für die Vorbereitung auf die Katastrophe, für die Reaktion während der Katastrophe und für die Erholung nach der Katastrophe. Die entwickelten Rahmenbedingungen bieten eine wichtige Hilfe für diejenigen, die im Katastrophenfall für das Verkehrswesen verantwortlich sind.

Der nächste Abschnitt der Arbeit gibt einen Überblick über die Verkehrs- und Transportprobleme bei Katastrophen. Diese Aspekte werden gemäß den möglichen Katastrophenauswirkungen auf die Verkehrsinfrastruktur, die Verkehrsmittel und die Nutzer bewertet. Die Probleme des Katastrophen- und Verkehrsmanagements und deren Bearbeitung werden anhand der Fallbeispiele Nagapattinam und New Delhi dargestellt. Hieraus wird der Handlungsrahmen für die operative Umsetzung des Verkehrsmanagements im Katastrophenfall entwickelt. Darauf aufbauend werden Visionen, Aufgaben, Ziele und Zwecke des Verkehrsmangements im Katastrophenfall definiert. Daraus ergeben sich wesentliche Hinweise, wie die Verkehrssituation bei Kastastrophen besser gehandhabt werden kann.

Ein entscheidender Teil dieser Forschungsarbeit ist die Entwicklung von 27 Verkehrsmanagementmaßnahmen. Dabei beziehen sich acht der Maßnahmen auf den öffentlichen Verkehr, zwei auf den nicht-motorisierten Verkehr, vier auf den motorisierten Individualverkehr, zehn auf multimodalen und intermodalen Verkehr sowie drei auf den Güterverkehr. Es wird ein qualitatives Modell entwickelt, mit dem die entwickelten Maßnahmen nach ihrer Anwendbarkeit und Effektivität bewertet werden. Gemäß dieser Bewertung werden die Maßnahmen in sechs verschiedene Klassen geordnet. Es wird gefolgert, dass die Anwendbarkeit der Maßnahmen verbessert wird, indem die Schwierigkeiten bei der Umsetzung reduziert werden. Daher werden

ergänzende Maßnahmen für eine verbesserte Anwendbarkeit von solchen Verkehrsmanagement-maßnahmen vorgeschlagen, die sich in der Bewertung als sehr effektiv, aber schwer umsetzbar herausgestellt haben. Da so das Bewertungsergebnis dieser Maßnahmen verbessert wird, können sie bei der anschließenden Formulierung der Verkehrsmanagmentstrategien mit berücksichtigt werden.

In dieser Arbeit werden neun Verkehrsmanagementstrategien entwickelt, um sowohl die Verkehrsnachfrage als auch das Verkehrsangebot in katastrophenanfälligen Gebieten zu beeinflussen. Bei der Entwicklung der Strategien wird die vorangegangene Bewertung der Maßnahmen berücksichtigt. Geeignete Maßnahmen werden vorgestellt, nachdem überprüft wurde, ob die Maßnahmen einer Strategie miteinander kompatibel sind. Die Verknüpfungen zwischen Verkehrsmanagementmaßnahmen, -modulen und -strategien werden ermittelt.

Die vorliegende Arbeit nutzt im Weiteren die Grundsätze der Szenarienplanung zur Beurteilung von Verkehrssituationen. Solche Beurteilungen helfen Verkehrsmanagern bei der Entscheidung über die Anwendung geeigneter Strategien, bei der Formulierung von Anforderungen an die Verkehrsmanagementmodule und bei Entscheidungen über den Einsatz von Verkehrsmanagementmaßnahmen. Die Verkehrssituation wird weitesgehend nach drei Faktoren beurteilt: die Auswirkungen der Katastrophe auf Verkehrsangebot und Verkehrsnachfrage, den Zustand der Verkehrssysteme im Katastrophengebiet sowie der Qualität des Verkehrsablaufs während der Katastrophe. Es werden Kriterien und Indikatoren identifiziert, mit denen die Verkehrssituation bei Katastrophen bewertet werden kann, und die Verknüpfungen zwischen diesen Faktoren werden dargestellt. Anschließend wird ein Modell zur Bewertung von solchen Verkehrssituationen entwickelt. Dafür wird ein Bewertungsindex ermittelt, der sich durch die aufaddierten Punkte aus Teilbewertungen der Situation und aus deren relativem Gewicht ergibt.

Schließlich werden für das Fallbeispiel New Delhi Vorschläge zur Anwendung von Verkehrsmanagementmaßnahmen entwickelt und in Beispielen beschrieben. Die Vorschläge beschränken sich dabei auf die vorher festgelegten Verkehrsmechanismen und -prozesse in New Delhi.

Die wesentlichen Schlussfolgerungen, die aus der Forschungsarbeit herzuleiten sind, werden jeweils kapitelweise dargestellt. Zudem werden die technischen Schwierigkeiten, die während der Untersuchungen aufgetreten sind und die daraus resultierenden Begrenzungen der Aussagen dargelegt.

Zum Schluss werden Vorschläge für weitere Forschung auf dem Gebiet „Verkehrsmanagement bei Katastrophen“ gemacht.

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List of Abbreviations

ADAC	Allgemeine Deutsche Automobil-Club
ADMN	Administrative Measures
ADRC	Asian Disaster Reduction Center
AHP	Analytic Hierarchy Process
ASB	Arbeiter-Samariter-Bund Deutschland e.V.
BIS	Bureau of Indian Standards
BRT	Bus Rapid Transit
CATS	Centralised Accident and Trauma Services
CMS	Changeable Message Signs
CO_2	Carbon Dioxide
CRED	Centre for Research on the Epidemiology of Disasters
db(A)	Decibels Acoustic
DDA	Delhi Development Authority
DDMA	Delhi Disaster Management Act
DDMP	Delhi Disaster Management Policy
DM	Disaster Management
DMF	Disaster Management Function
DMS	Dynamic Message Signs
DS	Difficulty Score
DSF	Disaster Support Function (similar to DMF)
DTC	Delhi Transport Corporation
DTM	Disaster Traffic Management
ECO	Economic Measures
EIA	Environmental Impact Assessment
EM-DAT	Emergency Database
EMF	Emergency Management Function (similar to DMF)
ES	Effectiveness Score
FEMA	Federal Emergency Management Agency
FT	Freight Transport
HAR	Highway Advisory Radio
HCBS	High Capacity Bus System

HOV	High Occupancy Vehicles
HPC	High Powered Committee
IGNOU	Indira Gandhi National Open University
IMT	Individual Motorised Transport
INFO	Information Measures
ITF	Integrale Taktfahrplan
ITS	Intelligent Transport Systems
IVHS	Intelligent Vehicle Highway Systems
KatS-Stab	Katastrophenschutzstab
LOD	Level of Difficulty
LOE	Level of Effectiveness
LOS	Level of Service/Level of Situation/Service Level
MCD	Municipal Corporation of Delhi
MIM	Multi-modal and Inter-modal Transport
NCHRP	National Cooperative Highway Research Program
NCMC	National Crisis Management Committee
NCR	National Capital Region of Delhi
NCR	National Capital Region of Delhi
NDMC	New Delhi Municipal Committee
NDMD	Natural Disaster Management Division
NGO	Non Governmental Organisation
NMT	Non-Motorised Transport
O/D	Origin and Destination
POV	Privately Owned Vehicles
PT	Public Transport
PTMC	Public Transport Management Centre
PWD	Public Works Department, Delhi
RDS	Radio Data System
ROW	Right-of-Way
RSA	Road Safety Audit
RSI	Road Safety Inspection
SL	Situation Level, Level of Situation
SOP	Standard Operating Procedures

SOV	Single Occupancy Vehicles
STEEP	Social, Technological, Environmental, Economic and Political Development States
TDM	Travel Demand Management
TEC	Traffic Engineering and Control Measures
THW	Technisches Hilfswerk
TIM	Traffic Incident Management
TM	Traffic Management
TMC	Traffic Message Channel
TSM	Traffic System Management
TV	Television
UNDP	United Nations Development Programme
UPSRTC	Uttar Pradesh State Road Transport Corporation
USAID	United States Agency for International Development
USDOE	United States Department of Energy
USDOT	United States Department of Transportation
UTM	Urban Traffic Management
VISSIM	Visual Simulation
VMS	Variable Message Signs
VSM	Verkehrs System Management
WC	Weight of Criterion
WHO	World Health Organisation
Wtmf	Weight of Traffic Management Factor

1 Introduction

1.1 Background of the Study

Natural and manmade disasters create several impacts on the transport system. The causes of impact are not entirely due to high intensity but also due to native vulnerabilities that exist in any urban transport system. These vulnerabilities increase the impact of a disaster and may make the disaster situation worse. Disaster managers follow two approaches towards reducing the occurrences of natural disasters. One approach is oriented towards the prevention of a physical disaster by controlling the geological and meteorological causes. Second approach is oriented towards the reduction of the impacts on the community to a minimum. In cases where the prevention of the occurrence of a physical disaster is impossible, emphases are made toward reduction of vulnerabilities. The reduction of vulnerabilities reduces the severity of the impact of a hazard on the society and thus prevents a hazard becoming a disaster.

One of many consequences of rapid urbanisation is the increasing vulnerability of populations to natural and technological disasters. Disaster management has emerged as an essential tool being available to urban planners to protect urban settlements. In recent years, new pro-active approach of disaster management is adopted. A more comprehensive pro-active approach focuses on continuous actions taken in anticipation of a disaster to economise on damages to people, and natural and built-up environments. The methodology adopted in this dissertation is to develop the understanding of the constraints and shortcomings of the reactive disaster management and to inculcate the culture of pro-active disaster management by proposing counter measures. By adopting this methodology, this dissertation utilises the comprehensive approach based on four process of disaster management which are:

- **Disaster mitigation**,
- **Disaster preparedness**,
- **Disaster response**, and
- **Disaster recovery.**

The role of transport in both natural and manmade disasters is both an under-addressed and critical issue for disaster management functions. The issues of transport whether related to transport development or traffic management, are still in the nascent stages of development. This dissertation provides an in-depth written discourse on the subject of traffic management in disasters. The purpose is to develop a concept of traffic management applicable for disaster situations. Therefore, this dissertation proposes the traffic management measures and strategies that could be implemented before, during and after the disaster.

In several academic literature revealing similar concepts of traffic management in disaster-like situations, the subject of traffic management is introduced to maximise the transport supply. In this dissertation, new traffic management concepts are introduced which also contribute to solve a range of traffic and transport problems using the adaptation of demand-side adaptation.

1.2 Motivations of the Study

The proper implementation of the disaster management functions in disaster response and disaster recovery is critical for the life and safety of many people. The transport functions must be planned and executed in a co-ordinated manner which should ensure the most timely and orderly movement of the impacted populations. However, in real-life conditions the transport sector very

often does not adequately contribute to the effectiveness of disaster management functions. This is primarily due to lack of understanding about the disaster impacts on the transport system and the role of the transport sector including the traffic management. Whether or not the transport facilities are directly affected by the disaster, the involvement of the transport sector is n in most disaster management functions. The following sections list some of many motivations to pursue this dissertation study.

Inadequate recognition of the role of the transport system

In disaster management plans, the issues related to traffic and transport are understated due to lack of understanding of the role of the transport sector in disasters. This is normally due to the involvement of several stakeholders in the process of disaster management which have insufficient control and coordination including stakeholders of traffic management. Currently in many countries, there is a lack of understanding about the potential of traffic management to provide quick disaster response and effective disaster recovery (NCHRP, 2003). Because of this, many misconceptions exist both in traffic management and disaster management. For example, one misconception is that role of transport is limited to the provision of transport infrastructure especially transport vehicles. Another misconception is that the problems of traffic management emerging in disasters are mostly addressed by the implementation of daily traffic management measures, which are often found ineffective for disaster situations.

Unprecedented traffic and transport problems

The traffic and transport problems during disasters are unprecedented. The transport situation in disasters is characterised by

- **large scale impacts on the transport system,**
- **poor transport development-state in the disaster-affected area, and**
- **poor transport system performance.**

Necessary transport resources are unavailable due to the deficit of transport supply as a result of disaster impacts or due to high traffic demand as a result of the change in travel patterns in natural or manmade disasters. The scale of traffic and transport problems in disasters presents unique challenges to traffic management (Litman 2006; C Goodwin 2002 et al.). But transport planning is still focused on solving the daily traffic problems only due to underestimation and insufficient awareness of the disaster impacts on the transport system.

High potential for application of traffic management

The transport development measures (in anticipation of disasters) do not protect and provide solutions against all disaster impacts. Moreover, it is inevitably impossible to develop infrastructure for all cases of disasters. Thus, the indispensable role of traffic management in providing transport situation-dependent measures is recognised. The following points rationalise and demonstrate the high potential of the application of traffic management (TM).

- TM is a powerful tool for achieving at a modest cost a variety of social, economic and environmental objectives of disaster management. TM is an effective and efficient option available for disaster managers.
- TM can be applied for a short to a medium term timeframe. This fact makes the application of TM suitable for disaster management.

- TM can use multiple technologies and its adaptation to traditional technologies is possible.
- TM is modular in structure both in terms of its application as TM modules and also in effective control and monitoring of the impacts created by its application. This fact makes the application of TM suitable for different phases of disaster management.
- TM offers a great flexibility of operations due to its possible quick intervention to support disaster response and recovery. This means that the traffic management strategies and measures can be activated and alternated for a given time and transport situation.
- TM is adaptive to alternate transport operations required for facilitating disaster management.
- TM is integrative and compatible with disaster management as a sub-function of disaster management.
- TM has an already available basic-framework which can be used to maximise the synergies.
- TM is indispensable to avoid the occurrence of secondary disasters (traffic incidents) and to ensure the safety to the traffic.
- TM has a strong potential to reduce the duration of long-term disaster recovery.

Traffic management shortcomings

Despite the high potential of traffic management to aid the disaster functions, traffic management is still too much unplanned due to following:

- **Lack of procedure:** In the previous occurrences of disasters, several problems were experienced by traffic managers due to unavailable procedures related to activation of traffic management in disaster response and disaster recovery (Safrin, 2004).
- **Lack of training:** Due to inadequate knowledge of disaster management processes, stakeholders of traffic management are untrained in implementing correct TM measures for various disaster situations (Holle, 1998 et al.).
- **Lack of organisation:** Due to the absence of organisation structure of traffic management in urban and inter-urban areas, traffic management lacks coordination and integration with the disaster management stakeholders. The lack of organisation is critical to the mobilisation of scarce transport resources (FEMA, 2005 et al.).
- **Lack of economic resources:** Traffic management requires alternate equipments and technology to ensure its effectiveness within disaster response and disaster recovery functions. Many underdeveloped countries do not have an access to the state-of-the-art equipments and technology (Cambridge Systematics Inc, 2004 et al.).

Thus the traffic management needs to be planned in order to overcome the complexities in the structure of traffic management, the unreliability in the application of traffic management and the legal provisions of the traffic management.

1.3 Key Research Questions

This dissertation thesis is aimed at answering several key research questions.

- What is state-of-the-art in disaster management?
- What is state-of-the-art in traffic management?
- What is the integration-framework for the integration of traffic management and disaster management?
- What are the traffic and transport problems and issues in disaster-affected or disaster-prone regions?
- What is the operational-framework of traffic management in cases of disasters?
- Which traffic management measures are effective and applicable in cases of disasters?
- Which traffic management strategies are applicable in cases of disasters?

1.4 Situation Assumptions

Multiple situation assumptions are made in this study that facilitated the development of traffic management framework of integration and operation. In order to indicate the challenges for the traffic management during disaster, a set of disaster and traffic situations assumptions are made. These assumptions were made about infrastructure, operation and organisation of traffic management. Some of these assumptions are:

- The transportation infrastructure will experience extensive damage which will affect mobility and accessibility. Local transport resources will be inadequate to meet the high traffic demand during most disasters. The transport sector will experience a state of in-equilibrium in terms of provision of transport supply and the generated traffic demand.
- The poor decision-making and poor coordination between stakeholders will affect the traffic and transport operations during disasters.
- The restoration of transport infrastructure and communications will improve the traffic flow. This improvement will assist in the widespread and timely distribution of disaster response aid to the disaster-affected or disaster-prone regions.
- The primary transport mode will be individual motorised transport in the disaster-affected region.
- When required, both public and privately-owned local transport resources will be made available for the duration of the disaster.
- Additional transport resources will be available by the neighbouring states and counties through mutual aid agreements and political involvement.

The other assumptions related to transport situation will be citied where required during the entire course of this dissertation.

1.5 Aim and Objectives of the Study

This study is aimed at the development of an integration and operational framework of traffic management for disaster situations. In order to achieve this aim the following study objectives are defined:

- To develop the practical understanding of the state-of-the-art disaster management and traffic management processes.

- To find possible relationships between disaster management and traffic management to present the integration between them and to develop an integration framework.
- To analyse and evaluate the traffic management problems and issues in disaster-affected or disaster-prone regions.
- To develop a traffic management operational framework that defines the goals and objectives of traffic management in cases of disasters.
- To select the possible traffic management measures for disaster situations.
- To formulate the transport supply augmentation and traffic demand reduction strategies for disaster situations.
- To develop an assessment model to validate the implementation of strategies and corresponding measures for hypothetical disaster situations.

1.6 Scope of the Study

The research area of this study is limited to the aim and objectives of the study. The integration framework (integration of traffic management with disaster management) presented in this study defines the scope of this study. The traffic management is limited to the surface transport modes especially road transport modes such as individual motorised transport modes, public transport modes, non-motorised transport modes and freight transport modes. In addition to the given modes, it also includes multi-modal and inter-modal transport.

The contents of this study (integration framework, traffic management operational framework, traffic management strategies and their assessment) are confined to disaster situations only. Where the transport development is considered as being a part of traffic and transport infrastructure development, this study only supports infrastructure development as a long-term option which does not conflict with the aim and objectives of disaster traffic management.

The study presents an overview of traffic management problems, measures, strategies, integration framework and operational framework for most disasters with similar characteristics. Thus, this study is not confined to any single disaster and therefore the variations of characteristics of disaster would be acceptable. Furthermore, this study is not confined to any specific disaster-affected region for the validation or implementation of the formulated strategies.

This academic study is an endeavour to understand the role, integration, operation, and strategies of implementation with respect to traffic management only. The study suggests the formation of a catalogue of traffic management measures. The traffic management measures in the catalogue are limited and it might include many other complimentary traffic management measures in order to support a given TM measure. The scope of this study is limited to theoretical findings that provide the concept of operations and general traffic management measures and strategies for disasters or disaster-like situations. Thus, this study is not a practising guideline for any governmental or non-governmental institutions.

1.7 Research Methodology

This study is based on data collected from both primary and secondary sources. While the primary data are gathered by a structured questionnaire (expert interviews) and the case studies, the secondary data are gathered through literature review and case studies from various institutions in

India and Germany. A brief description of the commonly applied methods in this dissertation is given in the following:

- **Literature review:** This method involves reviewing the academic and institutional literature mainly on disaster and disaster management, state-of-the-art traffic management processes and traffic management measures among other literature.
- **Case study:** This method examines a number of variables and involves in-depth examination of the problems, measures and strategies applications for case study cities. The case study cities also provide systematic way of analysing problems, collecting data and reporting of the results.
- **Expert interview:** This method involves questioning the experts from the concerned fields about their opinion and practices on disaster and traffic management.
- **Analogy:** This method involves the inferences deduced from two or more findings that agree with one another in some respects. In this study, some contents are drawn and adapted from various books, research papers, journals, periodicals, reports and other publications on disasters as well as on transport.
- **Simulation and Modelling:** These methods involve a development of models of states or processes that represent certain key characteristics or behaviours of a selected physical or abstract system. In order to understand the applicability of traffic management measures, the measure-assessment models are developed. In the similar manner, the situation assessment modules are developed in this study.

The study followed precisely the transport planning process as published by German Traffic and Transport Research Association (**FGSV-Forschungsgesellschaft für Straßen- und Verkehrswesen**, 2001), given in the Figure 1-1. The presentation of chapters of this dissertation is also based on sequence of steps of German transport planning process.

The orientation to this study is provided through literature review which indicates deficiencies of disaster management and traffic management processes. Literature review also indicates the legal requirements including vision, goals and objectives of disaster and traffic management processes management processes.

Disaster traffic and transport problem analysis is based on the literature review as well as case study cities problems analyses. A tsunami affected city in southern State of India Tamil Nadu known as Nagapattinam is selected for the identification of disaster management, traffic, and transport problems. Similarly the developed traffic management measures are checked for their applicability in another case study city of New Delhi, the National Capital of India.

Traffic experts are primarily selected from Germany, India and Japan. Expert interviews are conducted to obtain the importance of formulated goals of traffic management and their descendent objectives. Based on the expert interviews, the applicable traffic management measures are investigated and developed.

The disaster management, traffic and transport problems, and applicable measures for disaster-like events are compared using the methods of analogy.

Simulation and modelling methods are used to develop traffic management scenarios by combining approximate transport situations and applicable traffic management measures. Thus,

the developed traffic management scenarios provide decision-making on various issues of the selection of traffic management strategies for different transport situations.

1.8 Organisation of the thesis

This dissertation was initiated with the development of understanding the disaster and traffic management processes in real-life conditions which are presented in **Chapter 2** and **Chapter 3**. This part of the dissertation process involved largely the understanding of the aim, objectives, phases and functions of disaster management. The problems related to organisational coordination of disaster management stakeholders were also studied with respect to organisational structure of disaster management in Germany and in India. Similarly the aim, objectives, and functions of traffic management are studied with respect to the role of traffic management in disasters. This endeavour involved the study of the application of traffic management as a tool for disaster management. This part involved extensive literature reviews of examples revealing the traffic management application in disasters or disaster-like situations. A comprehensive involvement of traffic management modules and their descendent traffic management measures and sub-measures is also described.

The process of problem analysis involved the methods of analogy to provide the potential problems of disintegration of the disaster and traffic management processes and organisations. The integration framework is presented in **Chapter 4**, which provides the integration and orientation (pro-active and reactive) of traffic management in four disaster management phases (disaster mitigation, disaster preparedness, disaster response and disaster recovery). The aim, objectives and sub-objectives of traffic management in the processes of disaster mitigation, disaster preparedness, disaster response and disaster recovery are presented.

Chapter 5 is an overview of traffic and transport problems in disasters. The process of problem analysis also identified the disaster impacts on the transport system (disaster impacts on transport infrastructure, transport modes and transport users including transport operators) and the prevailing transport boundary conditions in the disaster-affected and disaster-prone regions (legal, technical, economic and organisational issues). This process included both the primary data (Nagapattinam study area in India) and secondary data sources. The process of identification of problems involved several assumptions on disaster impacts, planning practices and measures implementation.

In order to present the realisation of traffic management in disaster transport situations, traffic management operational framework is developed in **Chapter 6**. In this chapter, vision statement, the mission statements, the goals and objectives of traffic management in cases of disasters are established. The establishment of goals and objectives of traffic management is a guide for analysis for policy makers including disaster managers and traffic managers. The same goals and objectives are used for qualitative analysis of traffic management in later chapters.

The next step of the planning process included the development of measures for the fulfilment of established goals and objectives of traffic management. A set of twenty-seven traffic management measures belonging to relevant transport categories e.g. public transport, non-motorised transport, individual motorised transport, multi-modal and inter-modal transport, and freight transport are proposed and presented in **Chapter 7**. This process included the qualitative assessment of TM measures. The qualitative assessment model is developed, which is based on two methods,

- estimation of relative weights of importance of goals and objectives of traffic management disasters, and

- rating of TM measures for effectiveness and applicability in disaster situations.

The first method involved expert interview and the second method involved a self conducted assessment based on subjective judgements on analogy, simulation and modelling. The qualitative assessment of measures provided the basis of the selection of TM measures (consideration and decision step of planning process). The basis of selection is the effectiveness and applicability scores, which provided six priority classes of measures for fulfilment of traffic management goals and objectives.

Chapter 8 provided the formulation of a total of nine traffic management strategies by combining different assessed TM measures which influence various components of the urban transport system. The development of the understanding of traffic management measures (especially the influence areas) and the use of available mechanisms are prerequisites for the formulation of TM strategies. A total of five TM strategies are formulated for transport supply augmentation and four strategies are formulated for traffic demand reduction. In addition, a total of twelve TM modules are presented to provide mechanisms and processes involved in the implementation of strategies in prevailing boundary conditions of disaster-affected or prone areas.

After the formulation of strategies, the qualitative assessment and the tools of assessment of transport situation are presented in **Chapter 9**. The tools of scenario planning are applied to validate the implementation of measures and strategies for hypothetical transport situations in cases of disasters. The factors, criteria, indicators of transport situation assessment are presented. An example of qualitative assessment of transport situation in Nagapattinam case study area is presented. The situation levels (SL (A) to SL (E)) are obtained while considering similar hypothetical disaster transport situations. The aim of this endeavour is to develop transport scenarios by combining transport situations and traffic management strategies similar to real-life conditions. The hypothetical scenarios indicate challenges of implementation of TM measures and strategies. Thus, they are useful tools to aid decision-making to aid traffic management in disasters.

Finally the proposals and recommendations are presented in **Chapter 10**. The proposals of strategies application are given for second case study area, Delhi. These proposals are grouped in 12 traffic management modules to indicate the mechanisms and processes required in Delhi. Last but not least, the main observations, facts, proposals and recommendations are explained chapter-wise in **Chapter 11**. The contributions, limitations of study, and recommendations for further research are also stated.

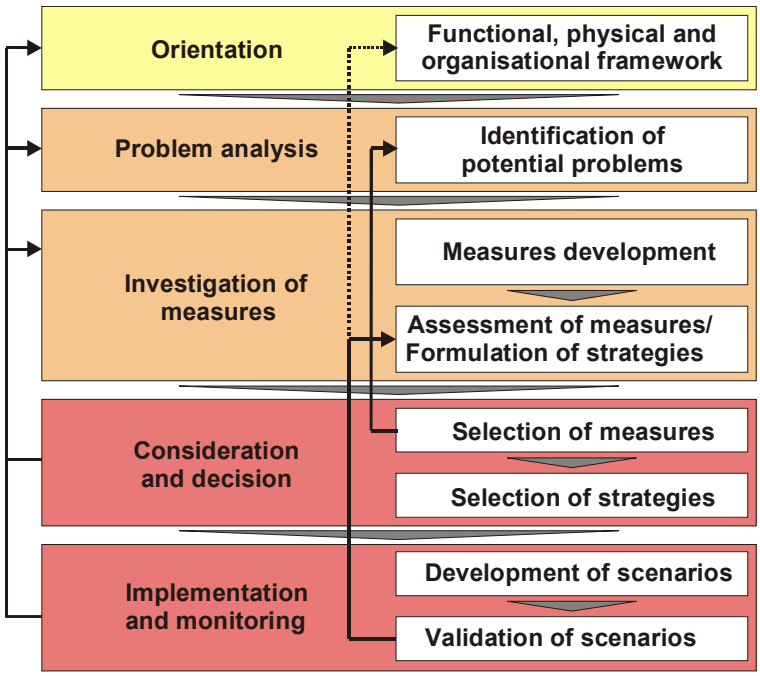


Figure 1-1: Transport planning process (FGSV, 2001)

2 Disasters and Disaster Management

2.1 Introduction

This chapter is an overview on disasters and disaster management both current and traditional. The definitions related to disasters and disaster management are presented. The process of the formation of disaster is reviewed. The general classification of disasters by the disaster managers and traffic managers is reviewed, and then selection criteria for the disaster classification adopted for this study are clarified. Disaster characteristics are studied based on four parameters

- **frequency of natural and manmade disasters**,
- **fatality of disasters**,
- **geographical impact of disasters**, and
- **economic impact of disasters.**

The conclusions are then presented based on the disaster characteristics. The processes and the sub-processes involved in the disaster management are introduced. The aims, objectives and the phases of the disaster management are established in the disaster management conceptual process. The traditional and contemporary approaches of disaster management are studied and commented. The stakeholders involved in the development and implementation of disaster management processes are identified. Finally, the status-quo of disaster management in India and Germany with respect to their organisational structures is studied and conclusions are made.

2.2 Disaster Definitions and Process of Disaster Formation

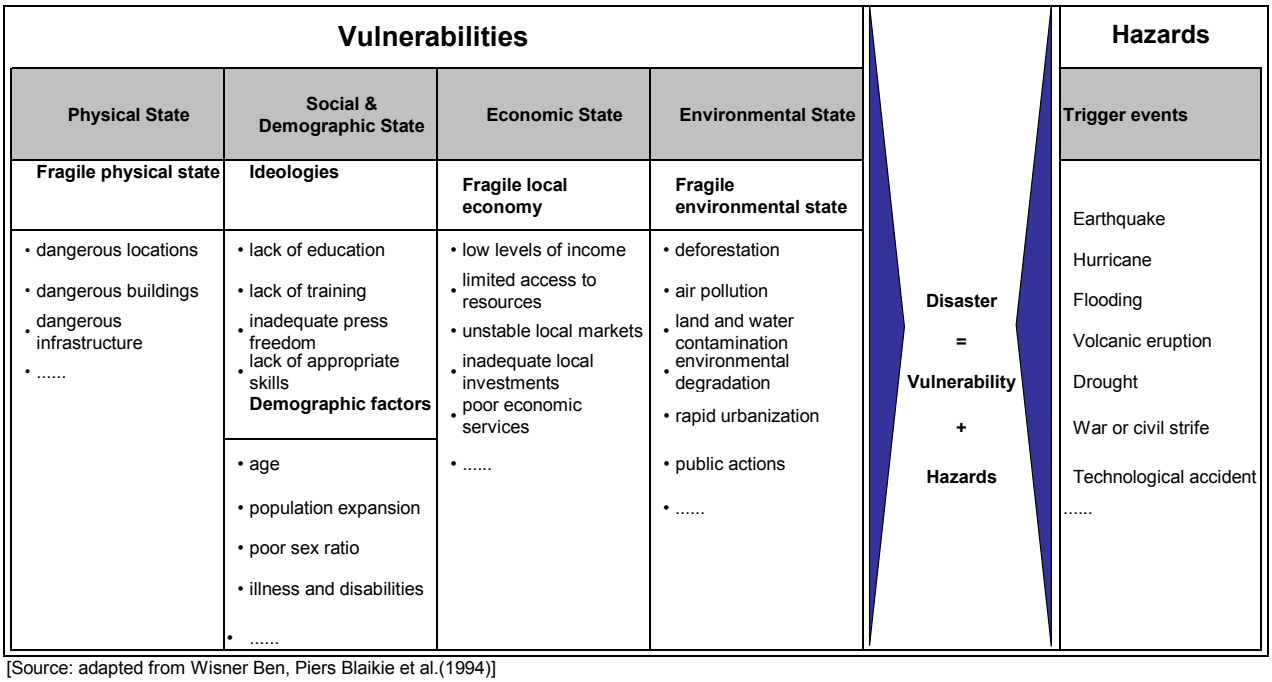
A **disaster** is a serious disruption of the functioning of a community or a society that causes widespread human, material, economic, and environmental losses. These losses generally exceed the ability of the affected community or society to resolve with only its own resources (WHO, 2001). Disasters represent potentially significant obstacles to economic growth and development in many countries. A disaster is a culmination of a hazard in vulnerable conditions. The formation of disasters is synonymous to "**fire and fuel**", in which fire represents hazard and fuel represents the vulnerable condition. Based on its source, a disaster can be classified as either a natural or a manmade disaster.

A situation is called hazardous because it poses a potential threat to human life, property or activity (IGNOU, 2005). Thus, the occurrence of a disaster reflects the state of a system with several associated vulnerabilities. This makes inter-regional or international interventions necessary. Munich Reinsurance Company refers to such disasters as great natural catastrophes (Munich Re, 2001).

Many different terms are used in publications to express the same meaning as the term 'disaster'. Such terms are: **incident**, **accident**, **emergency**, and **catastrophe**.

From the perspective of traffic managers, disasters are considered as incidents which reduce the right-of-way and supply capacity of transport system. A traffic incident management is a well-established module available to traffic managers which is often implemented in cases of disasters. Disasters affect many sectors including transport, and a proper description of the situation of traffic and transport is necessary. Literature review fails to describe the adoption of common criteria to define the traffic and transport situation in disasters. In order to define the traffic and transport situation in disasters, it is necessary to estimate the vulnerabilities in the transport sector in disaster-affected or disaster-prone areas.

The occurrence of a disaster is highly related to the **vulnerability** of the regions to disasters as explained in detail in Figure 2-1.



[Source: adapted from Wisner Ben, Piers Blaikie et al.(1994)]

Figure 2-1: Process of disaster formation

Vulnerability represents the state of the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of a community to the impact of hazard. Accordingly, the vulnerability can be described through the following states:

- **Physical state**: The causes of a physically vulnerable state are dangerous locations (flood plains, coastal zones, drought areas, seismic zones, etc.), dangerous buildings (dilapidated buildings, shallow foundation structures, etc.), and dangerous infrastructure (low quality roads, poor sewage flow, poor communications, etc.). All the given causes can be attributed to poor urban planning and weak implementation of building codes and regulations for disaster-resistant infrastructure as well as service.
- **Social and demographic state**: The causes of a socially vulnerable state can be attributed to ideologies which account for lack of education, training and special skills necessary for disaster management. The other causes can be explained through demographic factors such as age, population migration, poor gender ratio, population with illness and disabilities, etc.
- **Economic state**: The causes of an economically vulnerable state of people or societies can be attributed to low levels of income, limited access to resources, embargos, unstable local markets, low levels of production, etc.
- **Environmental state**: The environmentally vulnerable state of a region is attributed to natural and human processes or actions such as pollution (air, water and land), deforestation, land mining, rapid urbanisation, etc.

The poor state of development described by above given states in a region increases vulnerabilities and contributes to the occurrences of disasters both natural and manmade.

The Figure 2-1 provides examples of the process of disaster formation considering such states. (Wisner Ben, Piers Blaikie et al., 1994). Many disaster managers assume that the occurrence of most of the natural hazards cannot be prevented. One of many approaches of disaster management deals with the reduction of vulnerabilities to reduce the occurrence of disasters completely by reducing the vulnerabilities that could form a disaster.

2.3 Disaster Classification and Disaster Selection Criteria

The emergency events database (disaster database) maintained by the **Centre for Research on Epidemiology of Disasters (Catholic University of Leuven)** reveals the criteria for the selection and inclusion of disasters (EMDAT, 2008). These criteria of selection are:

- **number of people killed (10 or more)**,
- **number of people affected (100 or more)**,
- **a declaration of state of emergency**, and
- **a call for international assistance**.

The classification of disasters is a tedious task as disasters vary in origin and destructibility. The most prevalent form of classification is based on nature of the origin for example natural disaster or manmade disaster. Different studies have classified disasters based on the author's requirements. Similarly in this study, disasters are classified based on their impact on transport.

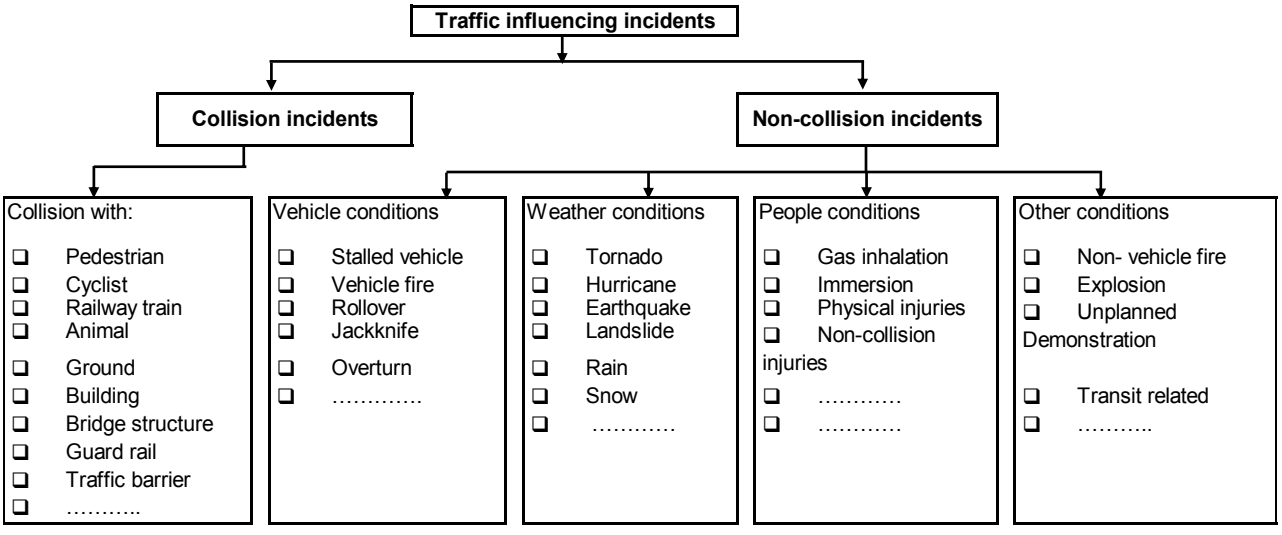
Traffic managers understand disasters mostly as **traffic-influencing events or incidents**. In the transport planning field, incident management is analogous to disaster management but on a relatively smaller scale of operations. Traffic incident management (TIM) is often misinterpreted and overstated as complete traffic management in disasters in some literatures. The comprehensiveness of disaster management including traffic management indicates that TIM only serves one of many requirements of disaster management. Thus, it is important to classify and understand disasters from a traffic and transport point of view for both the need of transport supply and the fulfilment of traffic demand due to disaster management requirements.

A typical traffic incident management plan emphasises a classification based on **collision and non-collision incidents**. The collision incidents are categorised based on the **type of collision** and the **source of collision**. Non-collision incidents are categorised based on four main causes such as **vehicle conditions**, **weather conditions**, **people conditions** and **other conditions** described in Figure 2-2 (Funke, 2001).

The above classification is quite comprehensive, encompassing most of the incident occurrences including disasters (NCHRP, 2003). The basis of the above classification is mostly from a traffic incident management point of view, and focuses on managing incidents (including disasters) only from the transport supply and traffic operations perspectives within a limited duration. The daily traffic incidents do not demand for special traffic management schemes or measures as they are managed by the traffic management authorities in a regular way. However, disasters (both natural and manmade) demand quick disaster response and disaster recovery operations which further require traffic management focusing on fulfilment of traffic demand. Disaster situations therefore obviously need special traffic management strategies to attain these functionalities. Thus, the traffic management in disasters should consist of transport supply augmentation strategies and also traffic demand reduction strategies to completely address the requirements of disaster management.

One of the research focuses of this study is the formulation of different traffic management strategies for various disasters. The study aims to formulate common strategies and disaster specific strategies based on disaster characteristics. The formulation of disaster specific strategies is possible with the complete understanding of the disaster impacts on the transport system. In this study, a hypothetical approach is followed which is described through various hypothetical assumptions on transport problems, transport performance, and transport development state (explained in the Chapter 9). In general, this study is focusing on disasters with the following characteristics:

- **Geographical scale**: This study includes the disasters which cover a large geographical area. Thus, it includes disasters which impact transport system both at urban level and inter-urban level. This leads to the development of traffic management measures for urban and inter-urban areas in Chapter 7.
- **Warning time**: This study includes both predictable and unpredictable disasters. The traffic management preparedness measures depend largely on the warning time of disasters. In cases with more warning time, traffic management measures are of a more proactive and planned nature. In cases where the warning time is limited the reactive measures are needed. In cases of predictable disasters, evacuations are more convenient unlike in unpredictable disasters. The TM measures in this study are developed for both predictable and unpredictable disasters.
- **Fatalities/Injuries**: The disasters which pose a definite threat to the lives and safety of people are included in this study. The TM strategies in cases of such disasters will consist of strict and unprecedented TM measures. This study thus proposes measures which are implemented in urgent disaster situations described by immediate loss of life and property.



[Source: adapted from Funke (2001)]

Figure 2-2: Traffic incidents classification

- **Traffic demand**: The disasters which generate an abrupt increase in the transport demand due to activation of disaster support functions such as medical care, disaster control, public works and engineering, etc. are included in this study. This study proposes TM measures

both for instant traffic demand and gradual traffic demand before, during and after the disaster occurrence.

- **Transport supply**: Disasters that either impacts the transport infrastructure supply or the traffic operations are included in this study. The disasters which results in decreased transport supply are included and traffic management measures are proposed accordingly. The proposed traffic management measures are applicable only when a potential exist for utilising the available though inadequate transport supply capacities.

Disaster	Geographical Scale	Warning time (Possibility and Duration of warning)	Probable deaths	Possible activation of Disaster Management Functions				
				Medical care	Disaster control			Public works and engineering
					Evacuation	Search & rescue	Quarantine	
TORNADO/HURRICANE	Very large	Usually (days)	Small to large	✓	✓	✓		✓
EARTHQUAKE	Large	None (no time)	Large	✓	✓	✓		✓
TSUNAMI	Very large	Short (hours)	Large	✓	✓	✓		✓
FLOODING	Large	Usually (days)	Large	✓	✓	✓		✓
VOLCANIC ERUPTION	Small to large	Usually (days)	Small to medium	✓	✓	✓		✓
WILD FIRES/ FOREST FIRES	Small to large	Usually (days)	Small to medium	✓	✓	✓		✓
HEAVY SNOW / ICE STORM	Very large	Usually (days)	Small	✓		✓		✓
LANDSLIDE/SNOWSLIDE /AVALANCE	Small to medium	Sometimes (hours,days)	Small to medium	✓	✓	✓		✓
BUILDING FIRE	Small	Seldom (no time, hours)	Small	✓		✓		
EXPLOSION	Small to large	Seldom (no time, hours)	Small	✓				✓
BUS/TRAIN/AIRCRAFT CRASH	Small to large	Sometimes (no time, hours)	Small to medium	✓	✓	✓		
NUCLEAR/OTHER RADIATION	Small to large	Sometimes (no time, hours)	Large	✓	✓		✓	
HAZARDOUS TOXIC RELEASE	Small to large	Sometimes (no time, hours)	Small to large	✓	✓		✓	
CIVIL STRIFE / WAR	Small to large	Usually (days)	Small to large	✓	✓			✓

Note:

Geographical scale : Small: ≤ $(1km)^2$; Medium:≥$(1km)^2$ and ≤ $(5km)^2$; Large:> $(5km)^2$
Warning time : no time, hours, days
Probable deaths : Small: less than 100; Medium: less than 1000; Large: more than 1000

[Source: adapted from Litman (2006)]

Table 2-1: Example of disasters characteristics

The objective of this selection is to categorise the disasters (natural and manmade) into groups that share the same characteristics and pose similar challenges in transport planning and traffic management. The possible activation of disaster management functions for various disasters is explained in Table 2-1 (Litman, 2006). These DMF's demand the development of new traffic management measures to improve the disaster management processes. Table 2-1 also categorised disasters based on the geographical scale, warning time, probable deaths and the possible activation of disaster management functions (DMF). The increased traffic demand in

disasters is attributed to the activation of various disaster management functions. Similarly, decreased transport supply is attributed to the possible impacts on the transport infrastructure (damages to roads, modes, terminals and traffic control devices) in the disaster-prone or disaster-affected region.

The Table 2-2 explains the impact of various disasters on transport supply and traffic demand. Qualitative impacts of disasters on transport supply are estimated based upon the impact on transport routes, transport modes, transport terminals (bus terminals, rail terminals and airports), traffic control devices and the driving conditions prevailing at the time of a disaster. Qualitative estimation of traffic demand is based on activities resulting form the activation of disaster management functions before, during and after the occurrence of a disaster. However, the impacts of disasters on the transport system may be varied and may not even display a similar pattern of traffic demand and supply as given in the Table 2-2. Transport situation is a qualitatively estimated based on estimation of impacts on transport supply and traffic demand.

Disaster	Transport Supply	Traffic Demand	Transport Situation
TORNADO/HURRICANE	●	●	●
EARTHQUAKE	●	●	●
TSUNAMI	●	●	●
FLOODING	●	●	●
VOLCANIC ERUPTION	●	●	●
WILD FIRES/ FOREST FIRES	◍	●	◍
HEAVY SNOW / ICE STORM	◍	◍	◍
LANDSLIDE/SNOWSLIDE/AVALANCE	◍	◍	◍
BUILDING FIRE	○	◍	◍
EXPLOSION	○	○	◍
BUS/TRAIN/AIRCRAFT CRASH	○	○	◍
NUCLEAR/OTHER RADIATION	○	○	◍
HAZARDOUS TOXIC RELEASE	○	○	◍
CIVIL STRIFE / WAR	○	○	◍

Note:

● **Very poor transport supply/Very high traffic demand/Critical situation**

◍ **Moderate transport supply/low to medium traffic demand/ Very poor situation**

○ **Adequate transport supply/low to high traffic demand/Poor situation**

Table 2-2: Qualitative estimation of transport situation

2.4 Disasters Characteristics

In this section, the compilation of data on natural disasters for all five continents namely: Africa, Americas, Asia, Europe and Oceania are studied. The data involved in the compilation have come from given sources and some data have been adapted and reproduced (Munich Re 2001; WHO 2001; CRED 2003; ADRC 2002, 2003, 2004). The characteristics of the natural disasters have been presented while considering three-year data (2002, 2003 and 2004) and four parameters, which are:

- **total number of disaster occurrences (frequency of natural disasters)**,
- **total number of people killed due to disasters (fatality of natural disasters)**,
- **total number of people affected (geographical impact of natural disasters)**, and
- **total amount of damages due to disasters (economic impact of natural disasters)**.

The following points were observed:

Frequency of natural disasters: Trend of the reported disasters shows the increasing occurrence of natural disasters (see Figure 2-3). The literature describes the inherent causes of disaster as global climate changes, environmental and ecological imbalance, increasing population density, improper urbanisation, deforestation and desertification (Carter 1992; Wisner Ben, Piers Blaikie et al. 1994; Munich Re 2001; WHO 2001). The compounding effect of these factors, results in human suffering, deaths, and economic losses due to natural disasters. Floods were the most frequent type of disasters in the year 2002, 2003 and 2004. Windstorms and earthquake came next in the order of occurrences. This phenomenon highlights the importance of these disasters for disaster management. Special emphasis is needed for such recurring disasters in disaster-prone areas in the disaster management plans.

Fatality of natural disasters: An earthquake is the most devastating disaster known to mankind. From the analysis of available data for the given years, it is revealed that earthquakes killed the most people, followed by extreme weather conditions and then floods.

Geographical impact of natural disasters: It is revealed from the data that floods affect the most people worldwide followed by drought and windstorms. According to the definition adopted by EM-DAT (CRED 2003)**,** the total people affected is the sum of people injured, homeless people and people affected by other means due to the same disaster. Disasters affect the people by destroying the houses and leaving the people homeless. This is mainly due to direct impact of the floods on people, which leads to short-term as well as long-term migrations in search of safe and secure living conditions.

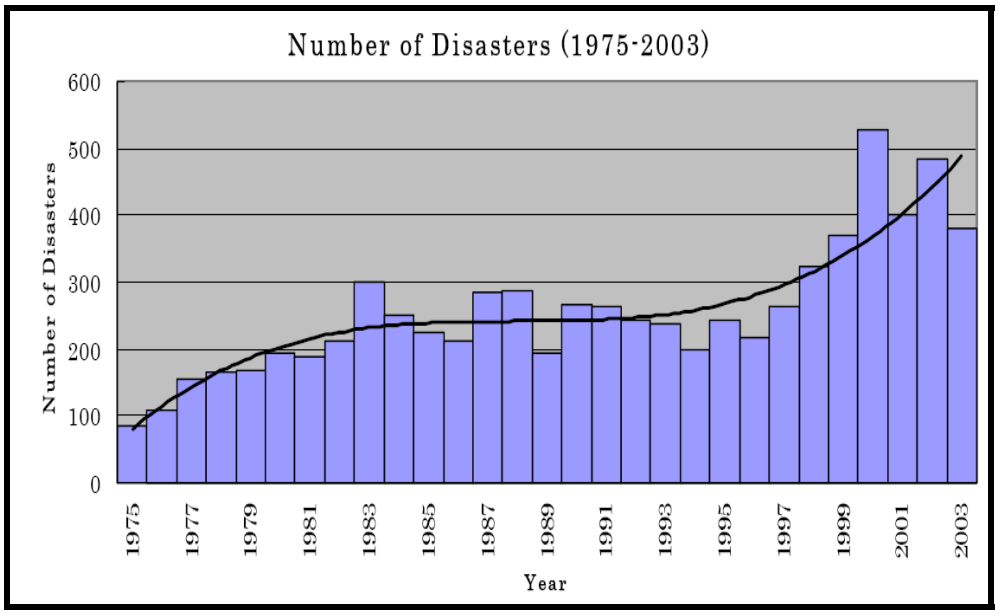


Figure 2-3: Worldwide number of registered disasters 1975 to 2003 (ADRC 2003, 2004)

Economic impact of natural disasters: Although Earthquakes account for more deaths than floods, windstorms and floods accounts for more disaster damages than earthquakes. These damages are quantified in terms of infrastructure damage and disruption, and the loss of economic activities during the disaster period.

From the analysis it is concluded that floods are the most frequent of all disasters. Floods are the most fatal disasters. Floods also have the widest area of impact when considered other disasters in all continents. Last but not least, floods cause the most damages world-wide.

Three disasters demand special consideration in disaster management planning world-wide which are: (i) Floods, (ii) Cyclones and (iii) Earthquakes.

It is noticed that the total damages resulting from disaster events vary significantly between the developing and the developed world, as does the ratio between the numbers of those affected and killed. For example, the databases on natural disaster in 2003 reveal that Asia is the most disaster-prone region in the world. The majority of the disasters (36%) occurred in Asia in the year 2003. This has surpassed the disaster occurrences in previous years. It is followed by Africa, America, and Europe respectively. Oceania stands as the least affected area in the world accounting for only 5% of the total natural disasters.

Accordingly, the majority of the people killed by natural disasters in the year 2003 lived in Asia with 57% of the total deaths by natural disasters in the world (decreased from 78% from the previous year). Another significant region is Europe with 35% of total deaths from disasters especially due to occurrence of the heat-wave conditions that hit Europe in 2003 (2% increase from the previous year 2002). The databases on disasters demonstrate that Asia experience most vulnerable conditions and severe disasters in the world. The amount of damages that the Asian-region encounters is approximately 40 % of the overall disaster damages in the world.

2.5 Disaster Management

Introduction

Disaster-affected or disaster-prone regions pose a serious threat to sustainable development. Sustainable development is not possible, unless proper disaster management is adequately acknowledged and practiced to eliminate or reduce the impacts caused by disasters. Disaster-affected or disaster-prone regions also expose the intrinsic vulnerabilities due to the existing physical, social, economic and environmental state.

The importance of the vulnerability suggests town planners and regional planners must consider the disasters in their planning approaches and methods. The subject of disaster management (DM) needs to be included in the process of urban planning and other planning areas. **"Disaster management means a continuous and integrated multi-sectoral, multi-disciplinary process of planning and implementation of measures aimed at prevention & mitigation, preparedness, response and recovery of disasters"** (Green Paper, 1998).

In the process of disaster management the holistic approach should be adopted; and the governments, institutions and agencies (disaster management stakeholders) should be reorganised for a more effective response and recovery from natural and manmade disasters to provide for more integrated prevention, mitigation and preparedness in anticipation of disaster. Disaster management therefore refers to programs and measures designed to prevent, mitigate, prepare for, respond to and recover from the effects of disasters. In cases where the underlying causes, intensity, and time of occurrence of disasters are not fully known, disaster preparedness measures are practiced. For example the occurrence of natural disasters such as earthquakes and hurricanes is not preventable; the approaches of DM are oriented towards the mitigation of impacts of such disasters on the habitats to minimum. An example of a preventive measure adopted in flooding is changing the course of the river. However, in cases where river courses cannot be changed, preparedness measures are adopted to minimise the flood impact on humanity and property. In the traditional approach of disaster management, the actions or measures of disaster management were limited to the disaster response and the disaster recovery. Contrary to this traditional approach, a contemporary approach is being developed and followed which emphasises the prevention of occurrence of a disaster through the implementation of effective mitigation and preparedness measures. However, a lack of systematic approach, co-ordination, committed

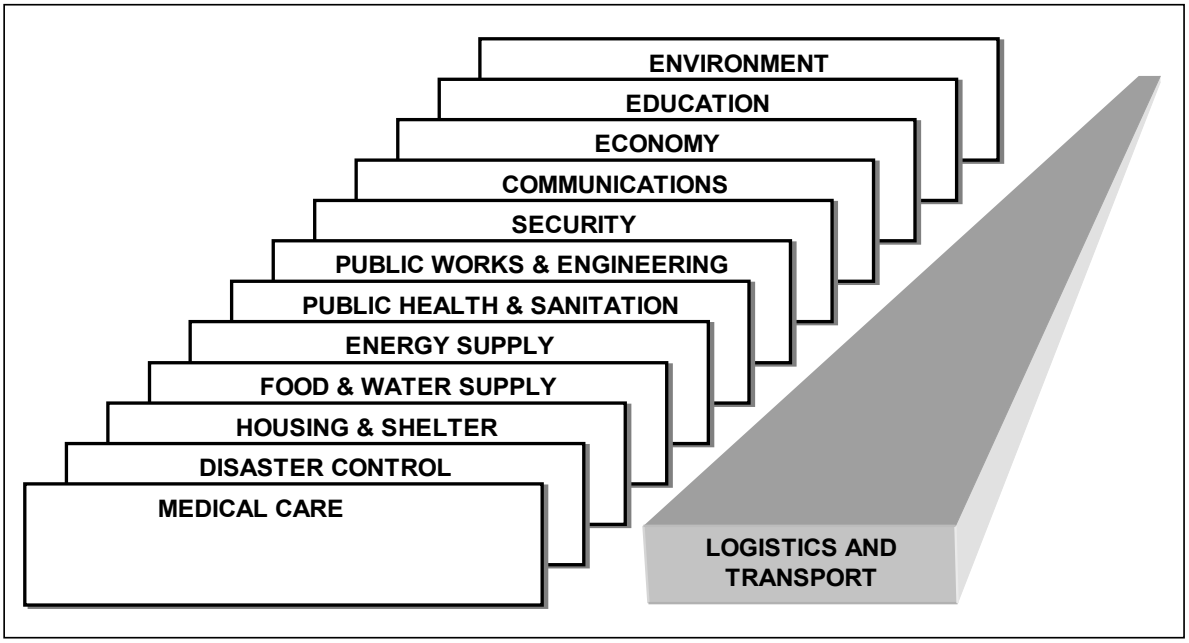
research, and developmental inputs are some challenges for an effective disaster management (Sahni and Ariyabandu, 2003).

Disaster management functions

In any form of governance, there are responsibilities that a government promises to its citizens. The governments are obligated to ensure the safety of the human settlements and to provide assistance to all the citizens in disasters without failure. The main aim of disaster management, and one of its strongest links with development, is the promotion of sustainable habitats and their protection and recovery during and after disasters (Warfield, 2003). Such orientations are revealed in the legal or non-legal framework of disaster management policies and disaster management acts (NDMD, 2004).

Disaster management is an inter-disciplinary system of many stakeholders at local, regional, national and international levels, which is explained later. A common characteristic of an interdisciplinary system is that an individual system is either a part of another system or vice versa. Functionally, disaster management is one of many interdisciplinary systems that allow settlements to exist. Disaster medical support system, disaster control system, supply systems during disasters, transport system, and telecommunication system are examples of sub-systems attributing to disaster management system. Many authors explained the functions of various departments involved in the disaster management (e.g. Sundnes 2002; FEMA 2003; Sahni 2003; NDMD 2004).

Figure 2-4 illustrates the basic societal functions of disaster management referred in this study as **disaster management functions (DMF)**. The disaster management functions reveal the responsibilities and duties that governments need to perform in order to provide safety and security to their citizens. Disaster support functions are essential functions which are necessary for the development and implementation of disaster management processes. They include essential services which are required before, during and after the occurrence of disasters. Most disaster management activities are oriented on these functions.



[Source: adapted from Sundnes and Birnbaum (2002)]

Figure 2-4: Disaster Management Functions

Likewise, the national response plan of the United States Federal Emergency Management Agency (FEMA) identified 14 emergency support functions (equivalent to disaster management functions). These functions represent specific response activities that are common to all disasters.

Each emergency support function comprises one or more primary agencies serving as the lead agency and also several other agencies and organizations which provide support. The Emergency Support Function or "ESF" is a mechanism that consolidates multiple agencies that perform similar or like functions into a single, cohesive unit to allow for more effective management of emergency response functions. The ESF concept was developed by the FEMA in the late 1980s to address the potential management concerns that would be necessary to coordinate a federal response to a disastrous earthquake in California. The ESF identifies transport as the first emergency support function providing support to two-thirds of the other emergency functions, thus depicting area of transport an utmost necessity. Therefore, transport is established as a support function for disaster management. Most recently disaster plans have started addressing the need of transport supply for disaster management. However, application of traffic management during disasters is still in the nascent stages of development and integration within disaster management in many disaster-prone countries.

Aims, objectives and phases of disaster management

The primary **aim** of disaster management is to promote the sustainable human habitats and their protection and recovery during disasters (Warfield, 2003). The secondary aim is to *ensure the safety and development of habitats in disasters*.

The disaster management has following **objectives**:

- **To avoid or reduce the impacts of disasters**,
- **To assure prompt assistance to the victims**, and
- **To achieve rapid and effective recovery**.

These objectives of fulfilled in one or more **disaster management phases**. The most general form of a disaster management cycle comprises four phases; namely

- **disaster mitigation**,
- **disaster preparedness**,
- **disaster response**, and
- **disaster recovery**.

However, many alternative forms of DM processes and phases are stated in different publications. The contemporary DM literature recognises the importance of disaster prevention and promotes prevention above all efforts of DM. In cases where a disaster cannot be prevented by scientific or human intervention, DM emphasises mitigation of the disaster impacts to the minimum. Disaster preparedness acknowledges that whilst it is impossible to completely prevent a disaster or mitigate its effects, DM necessitates adequate preparedness to respond to a disaster and a quick recovery from the disaster impacts. Disaster prevention or mitigation and disaster preparedness include measures implemented in anticipation of a disaster and thus are proactive in nature. On the contrary, disaster response and disaster recovery measures are mainly reactive in nature. A brief description of the aims and measures in the different processes and phases of disaster management is given in the next sections.

DISASTER MITIGATION: Disaster mitigation is the first sub-process of the disaster management process and is aimed at mitigating the impacts created by a disaster on the community. The sub-process pursues a structural and a non-structural approach towards mitigation. Disaster mitigation measures include enforcement of building codes, zoning and land-use management, building-use regulations and safety codes, preventive health care, and public education.

The sub-process of disaster mitigation consists of incorporation of appropriate measures at national and regional development planning levels. The effectiveness of disaster mitigation will also depend on the availability of information on hazards (hazard assessment and mapping), (elements at risks), (a vulnerabilities assessment), and the countermeasures implemented. The measures in this phase are more curative than preventive in nature.

DISASTER PREPAREDNESS: Disaster preparedness is the second sub-process of the disaster management process and is aimed at ensuring preparedness in anticipation of a disaster. Disaster preparedness constitute measures which enable governments, organisations, communities and individuals to respond quickly to disaster situations (Carter, 1992). Disaster preparedness includes the formulation of preparedness plans, conducting emergency exercises/training and the development of warning systems among others.

DISASTER RESPONSE: Disaster response is the third sub-process of the disaster management process and is aimed at providing the prompt assistance to the disaster-affected or disaster-prone people. In this phase and sub-process the measures are focused to minimise the impacts created by a disaster occurrence. The response measures include providing medical assistance, disaster control, providing food and water supplies, and the evacuation of victims among other assistance.

DISASTER RECOVERY: Disaster recovery is the fourth sub-process of the disaster management process and is aimed at recovering the affected community to a normal or an improved level. This phase is mainly focused on ensuring the rapid and effective recovery from the impact of a disaster. This phase and the sub-process consists of reconstruction and rehabilitation measures, such as building of temporary housing, distribution of grants and providing medical care. In the contemporary approach of disaster management, post-disaster recovery is considered not only as a disaster management activity but also a development activity as it integrates with the overall development process and seeks out opportunities for more effective reconstruction and development for future disasters (IGNOU, 2005). In some publications disaster development is even indicated as a separate phase after disaster recovery (Carter 1992; Green Paper 1998; Disaster Management White Paper 1999; Sahni 2003).

In Figure 2-5, the disaster management conceptual process is shown in four phases in which aims and objectives are described with specific measures for each disaster management phase and the sub-process. In practice, most of the disaster management phases generally overlap, and it is difficult to estimate the exact duration of each disaster management phase. For example the disaster response phase is mostly urgent and generally a short-term phase, but estimating the exact duration of disaster response phase will depend on type of disaster, impact, and geographical scale. The other phases of the disaster management are long-term phases such as disaster mitigation, disaster preparedness and disaster recovery. Post-disaster phases especially disaster recovery (restoration, rehabilitation and reconstruction) need not be merely viewed as a disaster management activity, but also as a development activity. The developmental approach of disaster recovery is applicable to the process of disaster mitigation and preparedness and should be incorporated as a part of development plan of the disaster affected area.

Approaches of disaster management

The basic disaster management phases described in the above section do not always occur in isolation or in a given precise order. Therefore, the disaster management cycle should be considered as a continuum of interlinked activities and should not be considered as a series of events that begin and end with each disaster phase. This section discusses the traditional and contemporary approach of disaster management. In the traditional approach disaster management is carried out in phases namely: pre-disaster risk reduction phase and post-disaster recovery phase, which follow each other in a sequence. This continuum or cycle shows that mitigation and preparedness always precede a disaster as shown in Figure 2-6.

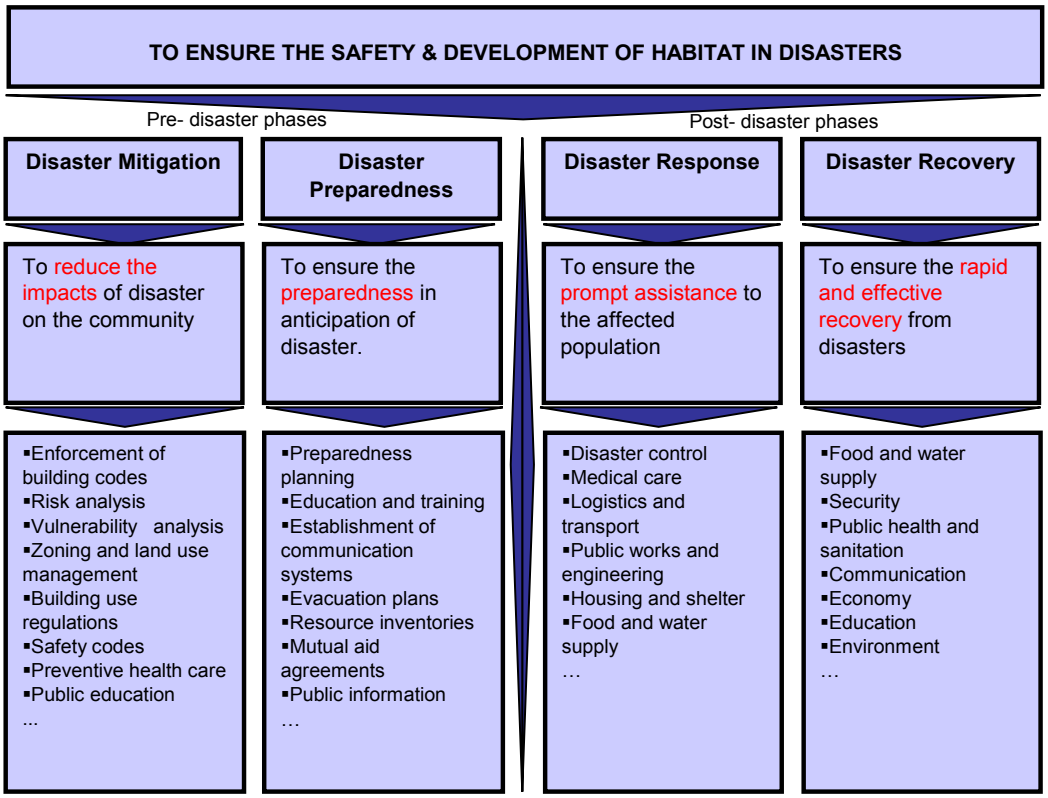


Figure 2-5: Disaster management conceptual process in four phases

The phases of this process are discrete and have no bearing with the following or preceding phases. The contemporary approach considers the sub-processes of the disaster management process as simultaneous implementation. In the contemporary approach, the disaster management sub-processes are followed parallel in contrast to the sequential nature of traditional approach. The different strands of actions or activities in the sub-processes are presented as strands which simultaneously expand and contract depending on the hazard and its associated vulnerabilities (Figure 2-6). Disaster management is considered a continuous but non-cyclic process in the contemporary model. This model emphasise the relevance of all individual activities in the sub-processes of disaster management. For example, in a disaster such as flooding, the “response” strand will expand to cope with the immediate effects of the disaster but over a period of time, the “recovery” strand including the “mitigation” strand will expand to adequately address the needs of the affected community. Unlike the traditional approach, contemporary approach acknowledges that disaster management usually includes a number of interventions and actions that may be occurring simultaneously and not always in phased successions. For example, in droughts, drought response, recovery, and mitigation may often occur at the same time.

The disaster management helix gives a better understanding of the process of disaster management (Saha, 2006). This model supposes that every disaster also brings positive development in the disaster management capacities of a system. The next time the disaster occurs, the system is more resilient and able to handle the impacts of disaster. In this way disaster management structure is similar to the helix explained in Figure 2-7.

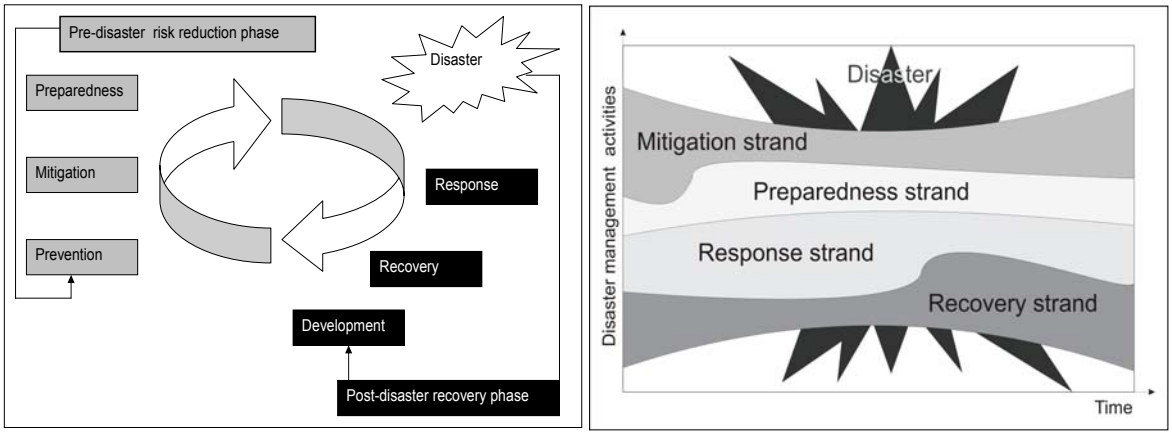


Figure 2-6: Traditional and contemporary approaches of disaster management

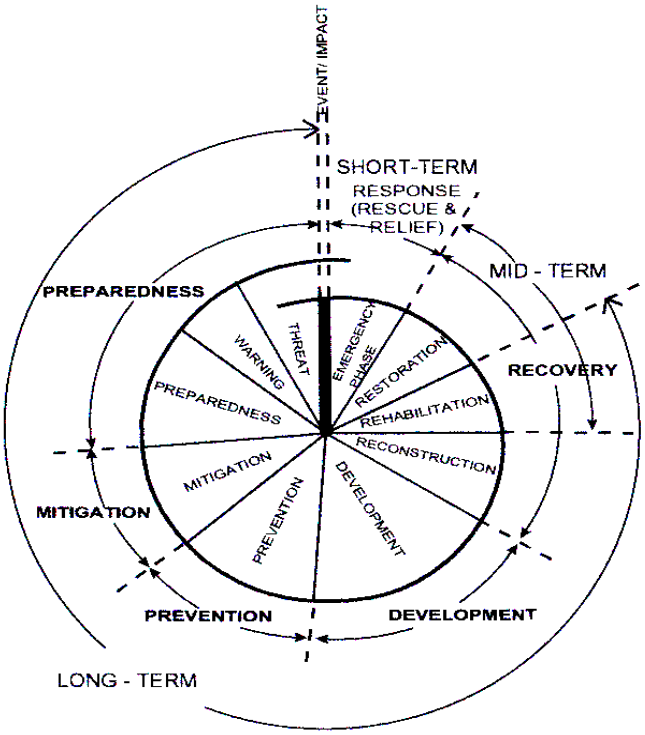


Figure 2-7: Disaster management helix (Saha, 2006)

Literature indicates that despite the existence of different approaches to disaster management, disasters are often managed inefficiently. Since disasters differ in geographical areas and impacts on people and property, it is relatively difficult to define and set the actions in a generalised form. However, the models provide some understanding about the methods, sequences, approaches, and activities involved in the sub-processes of disaster management. The pre-disaster measures of preparedness, mitigation, and prevention reduce the vulnerabilities of the disaster area to a

great extent and also assist the success of measures in post-disaster phases. The old saying that "prevention is better than cure" is true for disaster management, as well.

Stakeholders of disaster management

Generally, it is the responsibility of civil administrations to manage both natural and manmade disasters. In some countries, the assistance of armed forces is sought to manage disasters. Most disasters are dynamic and vary considerably in the characteristics that are defined by geographical scale, warning time, duration and impact on people. The disaster management processes thus require the cooperation of many different stakeholders from various disciplines.

The involvement of stakeholders largely depends on the type of disaster management functions activated. The stakeholders of disaster management typically includes the district administration, military and para-military forces, various ministries and departments at the Central government and State government levels, non-governmental organisations, and international agencies. Many countries have a well-defined organisational structure to manage disasters (Green Paper 1998; Ministry of Internal Affairs 2002; NDMD 2004). Depending on the disaster types, different departments are assigned responsibilities to mobilise resources at the appropriate levels. The involvement of non-governmental organisations (NGO) or private organisations is observable as a vital part of disaster management. Their involvement is largely observed to increase the disaster management capacities of governments. For example, the involvement of international agencies as the UNDP, USAID, Red Cross, and Oxfam, among others, assists in the increase of disaster management capacities. Similarly, the role of the media is observed in both factual and ethical reporting of disaster situations. An overview on the disaster management stakeholders and their relevant tasks is given in Table 2-3.

Disaster management in India and Germany status quo

This section describes the organisational framework of disaster management in Germany and in India. It aims at understanding the existing framework of disaster management functions in both countries and state deficiencies in the disaster management capacities with regard to stakeholder's involvement.

Disaster Management in India

India has been one of the most vulnerable countries in South East Asia to both natural and manmade disasters. The natural disasters in India occur due to its unique geo-climatic conditions. The manmade disasters have various causes and terrorism is among the important causes. A 60% of the total area of India is prone to earthquakes; over 12% (40 million hectares) is prone to floods. Furthermore, 8% is prone to cyclones, and 68% is susceptible to drought (World Bank, 2004).

Despite being one of the most vulnerable regions in the world, the Indian five-year fixed plans have historically not addressed the disaster management issues. The traditional approach has been limited to "calamity relief", which is mostly post-disaster response. Recently there has been a paradigm shift in approach of disaster management in India with focus on disaster prevention and mitigation. This is primarily due to vast economic gains and surging economy to meet demands of pre-disaster activities and processes. The super cyclone in Orissa on 29th Oct. 1999 and the Bhuj earthquake in Gujarat on 26th Jan. 2001 were major disasters which initiated the adoption of a multi-dimensional endeavour involving diverse scientific, engineering, financial, and social processes for disaster management.

Disaster Management Functions	Examples for Disaster Management Stakeholders	Examples for Tasks
MEDICAL CARE	• Medical Hospitals • Clinics • Volunteer Organisations	• Emergency Medical Care at site • Transport of Victims • Emergency Medical Care off site
FOOD & WATER SUPPLY	• Water Supply Authorities • Volunteer Organisations • Agriculture Departments	• Emergency Water Supply • Provide Food Supplies • Maintenace of Water Supply Lines
HOUSING & SHELTER	• Development Authorities • Public Works Departments • Private Builders • Public Schools	• Temporary Housing • Permanent Housing • Set up Temporary Shelters • Shelter of Evacuaees
TRANSPORT & LOGISTICS	• State Transport Authorities • Transport Departments • Freight Transport Operators	• Provision of transport supply • Traffic Management functions • Shipping and Handling of Disaster Aid
PUBLIC HEALTH & SANITATION	• Dispensaries • Health Departments • Municipalities Corporations	• Essential Sanitation Services • Insect and Rodent control • Emergency Mortuary • Inspection of Food, Milk and Water Supply • Disposal of Dead Animals and Biological Waste
ENERGY SUPPLY	• Electric Supply Authorities • Civil Supplies	• Restoration and Maintenance of Electric Supply Lines • Providing Kerosene & Other Fuel
DISASTER CONTROL	• Fire Departments • Residents, People, etc. • Police	• Fire Prevention and Supression • Hazardous Material Handling • Search and Rescue Operations • Traffic Management at site
PUBLIC WORKS & ENGINEERING	• Public Works Departments • Private Contractors	• Restoration of Essential Services • Damage Assessment Debris Removal
SECURITY	• Police • Military • Security Guards	• Law Enforcement • Crowd Control • Investigations Traffic Detouring
COMMUNICATIONS	• Information Centers • Radio Stations • Telecommunications	• Ensure Essential Communications in Disasters • Ensure Repair in Cases of Damage • Cable TV Emergency Message System Video Documentation of Disasters
ECONOMY	• Department of Finance • Banks • Financial Establishments • Insurance companies	• Maintain Records of Disaster Related Supplies • Provide Funds for Procurement of Disaster Supplies • Provide Funds for Disaster Related Projects
EDUCATION	• Ministry of Home Affairs • Non-government Offices	• Disaster Management Campaigns and Exercises • Public Awareness Camps
ENVIRONMENT	• Environment Departments	• Environmental Impact Asssesment • Determine the Structural Safety of Buildings • Provide Weather Related Information • Environmental Conservation

Table 2-3: Example of possible stakeholders and tasks under DMF's

A High Power Committee (HPC) was constituted by the Government of India for the formulation of disaster management plans for all the States of India. The HPC formulated common plans for 31 identified disasters. The HPC followed a multi-hazard approach in disaster planning, and various trigger mechanisms are set to ensure the efficiency of response activities following a disaster. A concept of the activation of resources required in various disasters is developed and is known locally as L concept. L concept has been developed to define the different levels of disasters to facilitate assistance to states and the centre. L0 to L3 levels are denoted to signify the severity of disasters and the demand for assistance from districts, states and the centre.

The responsible disaster management ministry in India is Ministry of Disaster Management which works under the guidelines of the Disaster Management Act, 2005. This act allows the establishment of disaster management authorities at central, state and districts levels. During a national level disaster, NCMC (National Crisis Management Committee), in consultation with the Indian Meteorological Department and various disaster management groups are instrumental in initiating a nation-wide support and coordination. The national Disaster Operations Centre is activated on orders from NCMC after the formal disaster declaration. The head of Disaster Operations Centre is responsible for overall coordination and decision-making at the Disaster Operations Centre. The organisational section of the centre has the support desks for logistics, facility management, finance and human resources and information coordination.

Fourteen **Disaster Support Functions** (DSF) have been identified for disaster management and each DSF has primary and secondary agencies. The primary and secondary agencies for each disaster support function are the respective ministries and authorities at various levels (central, state, or district). The responsible primary agencies together with the secondary agencies (ministries) are responsible for their respective tasks under each disaster support function. These agencies have authority to execute disaster-response operations to directly support disaster management. The National Disaster Response Plan describes responsibilities, checklists, handbooks, planning assumptions, activities, response, and deactivation for each disaster support function (NDMD, 2005). The central disaster operations centre is further assisted by neighbouring disaster control centre/s in unaffected state/districts depending on the disaster type. The Ministry of Defence has set up many army battalions in different disaster-prone zones to assist the disaster management.

Despite of available and adequate resources available in India, disaster management still lacks knowledge and implementation of disaster management measures. Most of the development in urban and sub-urban areas is being without **Bureau of Indian Standards (BIS)** standards. Lack of awareness regarding the vulnerabilities among the population is common. Indian disaster management lacks specialised systems such as for urban search and rescue capabilities. Furthermore, disaster management significantly lacks the coordination among stakeholders. The involvement of private organisations in the current disaster management organisation structure is limited.

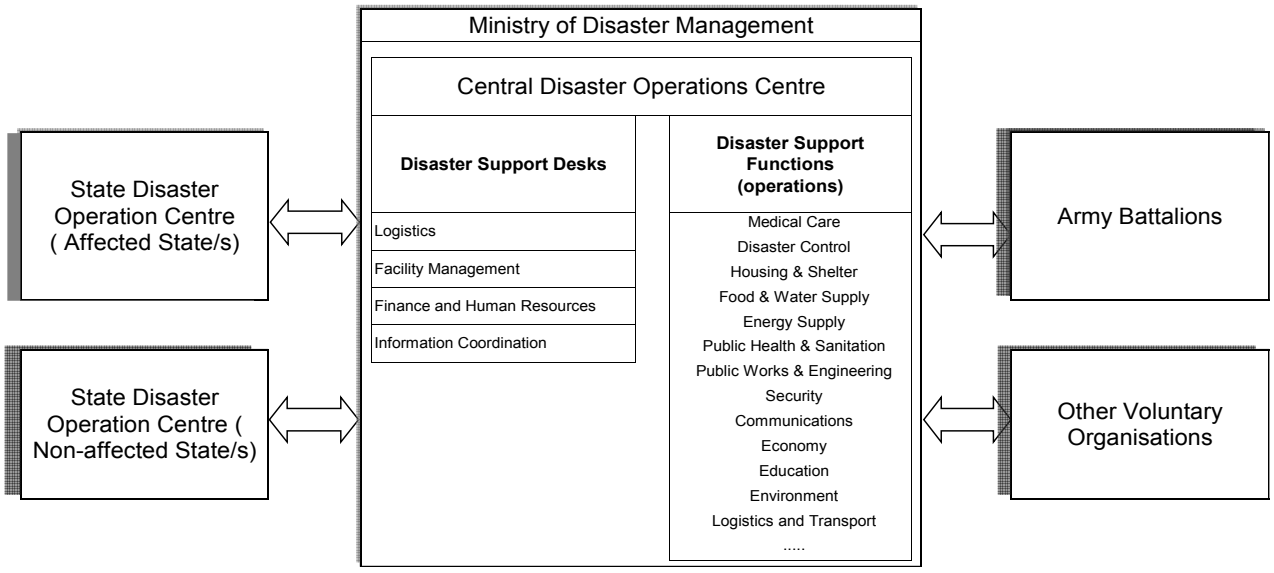
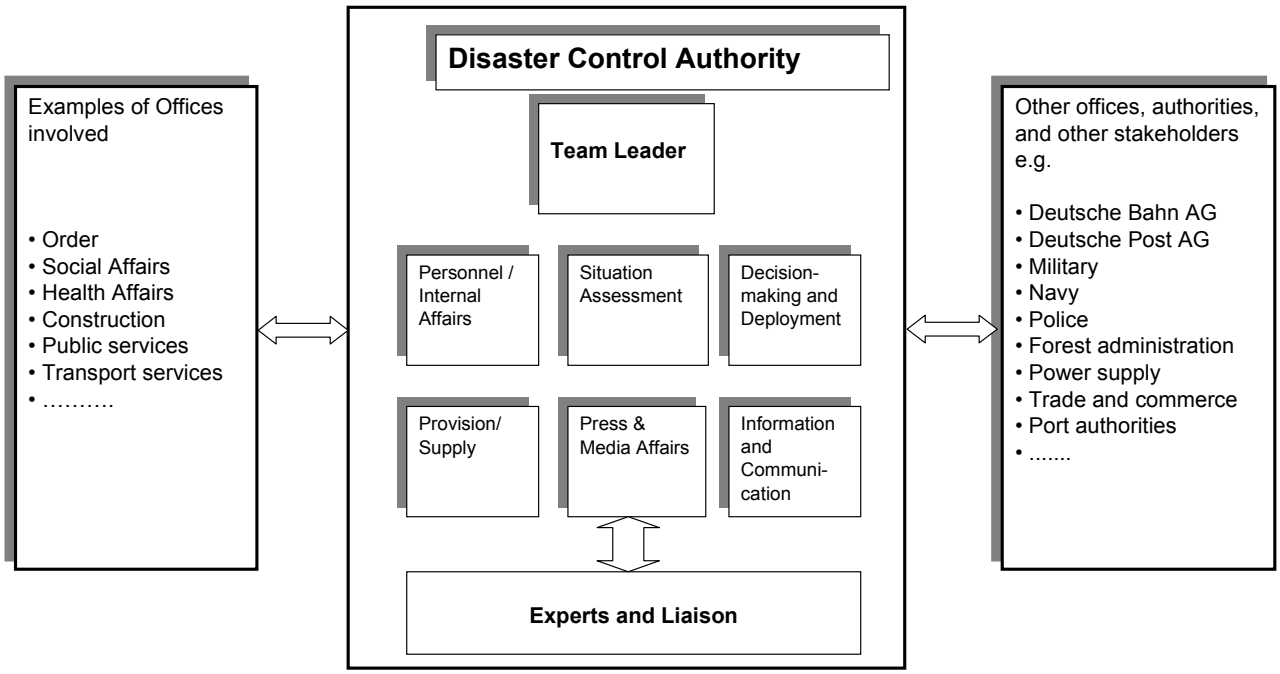


Figure 2-8: Disaster management organisational structure in India

Disaster Management in Germany

The disaster management in Germany falls under the responsibility of Federal Authority of Ministry of Civil Defence and Disaster Relief *(Bundesamt für Bevölkerungsschutz und Katastrophenhilfe)* whereas at the state level the Ministry of Interior is generally responsible for disaster management. Each Federal State of Germany has its own legislation that provides the framework for the command and organisational structure in incidents and in disaster situations. This command structure *(Führungstruktur)* describes the precise role and expertise of individuals, organised groups, and authorities at different levels of hierarchy (see Annexure A).

In daily incidents, the fire fighting services *(Feuerwehr)* and rescue services *(Rettungdienst)* are involved along with enforcement of law and order by police authorities *(Polizei).* The fire services are responsible for fire-protection and rescue of victims in cases of fires. Similarly the rescue services functions for all other accidents for example road accidents and chemical accidents. In Germany, the rescue services are merged to a large extent with voluntary organisations like Arbeiter-Samariter Bund (ASB), Red Cross, St. John Ambulance, etc. In addition to the given departments and authorities, the technical aid authority *(Technisches Hilfswerk, THW)* and the disaster control authority (*Katastrophenschutz stab or KatS-Stab)* participate in the management of disaster situations. THW provides technical and professional assistance such as infrastructure maintenance, repair and reconstruction. The KatS-Stab provides the liaisoning and management of resources. KatS-Stab is an association of six different members responsible for disaster management operations which are guided by a team leader and a group of external experts and liaison officers (Fig.2-9). Military involvement is generally required in cases where a lack of manpower and expertise is observed and depends on the geographical scale, magnitude and geographical location of the disaster. In some cases, the military leads the overall operation, but in most cases they assist the concerned authorities to cope up with the disaster situation. Based on the above framework, line of command is activated depending upon the type of event occurred (daily incident or disaster).



[Source: Katastrophen Schutz in Hessen Ministry of Interior and Sports, Aug 2002]

Figure 2-9: Disaster management organisational structure in German State of Hessen

It is evident that where the disasters are more frequent, the level of disaster planning and management is more developed. Even with the well coordinated approach in developed countries like Germany, the problems are still not completely rectified, and the threat of a hazard becoming a disaster always persists, though the vulnerabilities may not be as high as in some many developing or under-developed nations (Safrin, 2004). The disaster management organisational framework of Germany does not explain the level of inclusion of private and public sectors in disaster management. It also depicts several shortfalls in the coordination of different private and public organisations or groups. The inclusion of traffic and transport in the decision-making and deployment *(Einsatz)* is not reflected. Therefore, a comprehensive framework describing the role of individual organisations and sectors is required to manage disasters. This study however does not cover the organisational requirements of disaster management but intends towards strengthening the role of transport and hence the need for traffic management in disasters.

2.6 Summary

A disaster is a state or an event which disrupts the functioning of a community or a society. The local communities mostly cannot resolve of their own in the disasters. The disaster selection criteria in this study are based on the geographical scale of a disaster, the warning time of a disaster occurrence, the number of injuries and deaths resulting from a disaster, the traffic demand resulting from the activities of a disaster and the resultant transport supply available after a disaster.

The study on disaster characteristics revealed the foremost importance of floods. Similarly, cyclones and earthquakes were regarded equally important for disaster management. Disaster management is a well-established and integrated process of planning and implementation of pro-active and reactive measures. Unlike the traditional approach of disaster management, the contemporary approach considers the aggregation of disaster management phases and measures. The organisational structure of both countries India and Germany exhibited well-defined roles of disaster management stakeholders but failed to fully describe the involvement of the transport sector and many private stakeholders.

3 Traffic Management

3.1 Introduction

In many cases, the urban roads accommodate a traffic volume for which they were not initially designed or planned. This phenomenon is due to ineffective implementation of transport planning, poor transport development state and poor implementation of traffic management measures. The inevitable problem of congestion cannot be solved solely by transport infrastructure development due to the limitations of space, time and costs. Other methods that involve non-infrastructure development are needed to overcome the traffic and transport problems related to travel time, pollution, traffic accidents, and travel costs. Traffic management follows a non-infrastructure development approach to optimise the use of transport supply in proportion to the traffic demand. Some literature distinguishes traffic management and the transport development as alternatives to one another in terms of adoption of approaches to traffic and transport problems. However in this chapter, the descriptions of approaches of traffic management does not consider the application of traffic management measures as counter-measures to necessary transport infrastructure development in disasters.

The main purpose of this chapter is to provide an overview of traffic management organisation and processes. The chapter introduces the goals, objectives and the instruments of traffic management (TM). The classification of TM measures is presented, and the prerequisites for the application of TM measures are discussed. This chapter also explains the roles and responsibilities of potential stakeholders in traffic management. The current conflicts and risks pertaining to TM are discussed.

Further this chapter presents an overview of the present status of TM in Germany and India. The key differences in the application of TM in both countries are highlighted. An overview of the key influence areas of traffic management, TM influence types, and subsequently necessary TM modules are explained. The TM modules that are used for the measures of implementation in the existing TM framework are thoroughly explained.

3.2 Terms and Definitions

Academic and technical publications indicated that road traffic control was implemented world-wide and was mainly confined to inner city areas already in the Sixties and Seventies. Road traffic control was then termed as **“Urban Traffic Management - UTM”**. Later, in the United States and in Germany, the terms **“Transportation System Management - TSM”** and **“Verkehrs - System Management”** were used to describe the extension of the domain of traffic management from supply-side TM measures to demand-side TM measures for goal-oriented influence on all categories of traffic. The aim of TSM is to maximise the productivity and efficiency of the total transport system by coordinating the individual elements of a city-transport system including individual motorised transport, public transport, service transport, and freight transport. TSM is considered as a bundle of measures to make the most service-productive and cost-effective use of existing transportation facilities, services, and modes.

During the same period (1960-1980), the conventional approach of traffic management in Germany was focused on the coordination of traffic signals in the inner and outer city areas. This type of traffic control was termed as **“Verkehrsbeeinflussung”** which literally means the influence on traffic.

In the Eighties, many US provinces introduced traffic laws and regulations for the first time to reduce traffic by reducing the use of automobiles especially cars. These laws and regulations were

implemented under **Travel Demand Management (TDM)** programs. TDM is included in TSM, and provides the demand-side approach to traffic and transport problems. TDM is the reduction of automobile travel demand, or distributing the travel demand over different modes, spaces and times by altering people's behaviour (Orski, 2000).

The term "**Congestion Management"** was used to describe efforts towards reducing the congestion especially in peak hours.

In the US and in Netherlands, the term **"Mobility Plan"** is used to describe measures to change the travel behaviour of employees in order to reduce the commuter traffic.

Lately in Germany and in many other countries, numerous projects concerning mobility management have come into practice. **Mobility Management** includes detailed information dissemination and provision of transport services to the current and potential transport users. Some examples of mobility management are ticket pricing, seat reservation, real-time information on traffic conditions and parking opportunities. Mobility centres are established in many cities of Europe and the United States to provide detailed information services to current and potential transport users. Mobility management employs demand-oriented strategies to shift the use of **Individual Motorised Transport (IMT)** modes to **Public Transport (PT)** and other modes by effectively using information and communication technology. In a similar context of mobility management, the use of **transport telematics systems** is discussed for dissemination of real-time traffic information and the implementation of transport situation-based traffic control. In the United States, **"Intelligent Vehicle Highway Systems-IVHS"** are developed and referred to as **Intelligent Transport Systems (ITS)**. Equivalent concepts are being developed and practised in many countries as comprehensive application programs (ITS-Canada, ITS-Australia). Although the application of ITS has a lot of potential to influence the traffic demand, it is still not fully acknowledged as a traffic management tool. Some experts of the traffic management sector argue that it is possible to influence the traffic without the use of modern technologies (Boltze, 2003 a).

Various terminologies including urban traffic management, transport system management, travel demand management, congestion management and mobility management are used in different publications to describe similar influences on traffic demand and transport supply. According to Boltze, "**traffic management is aimed at influencing the traffic and transport through a bundle of measures to bring the traffic demand and transport supply in an optimised balance"** (BMVB, 2004). The task of traffic management involves an aim-oriented, systematic, anticipatory and informative preparation of measures to manage the traffic demand, transport supply, the current transport development, and its impacts. In order to fulfil established aims and descendent objectives, traffic management deploys coordinated applications of administrative, organisational, economical, technical and information measures to provide solutions to specific traffic and transport problems and situations. Infrastructure development measures such as infrastructure expansion or redevelopment are part of the traffic infrastructure planning measures and these measures are not included in traffic management. Traffic management may include measures from other non-transport disciplines which have strong influence on traffic and transport. Such measures can increase the effectiveness and applicability of traffic management measures e.g. change of settlement and location structures by effective land-use planning measures or some political measures.

Some academic literature limits the scope of traffic management to transport supply addition or augmentation. However in this study, traffic management will be considered both for augmenting the transport supply and reducing the traffic demand for various disaster situations.

In order to improve the clarity of scope of traffic management and to consider the impacts of the combination of measures, the structure of traffic management can be classified at different levels. These levels are:

- **Long-term measures**: are oriented towards the mobility development and organisation of overall transport system. These include measures that influence the traffic behaviour of the transport user in a long-term such as driver training programs, traffic education and traffic information.
- **Mid-term measures**: are oriented towards the control of traffic and traffic processes with respect to targets and strategies that are being discussed in a long-term. This group includes measures that influence the traffic behaviour of the transport user in medium term such as traffic laws and regulations, economic incentives and disincentives, preferential incentives and disincentives, and traffic information.
- **Short-term measures**: are situation-specific measures and are largely reactive measures to solve the current traffic problems or situations. These include “on-trip” measures and these measures control the traffic processes and the behaviour of transport users based on real time traffic conditions (such as dynamic message signs for traffic control and highway advisory radio for traffic diversions).

The above grouping of measures based on time-scales distinguishes traffic management measures based on the content and action areas of measures. The long-term measures are part of classical transport planning. Another type of classification of TM is based on the adaptability of TM measures as given below:

- **Static traffic management** consists of measures, which do not adapt to the current traffic conditions, but influence the traffic and transport fundamentally. In a static traffic management, the traffic managers must specify type and scale of impacts prior to their implementation. The static traffic management is less flexible and less error-prone.
- **Dynamic traffic management** consists of measures which adapt to the current traffic conditions. In a dynamic traffic management, traffic managers create measures without specifying the type and scale of impacts prior to their implementation. The dynamic type of TM includes flexible programs which can be implemented based on a particular situation to collectively influence a larger number of transport users.

In this chapter, the term **“traffic”** is used to define the change of place of people, goods, messages and energy.

The term **“transport”** is used to denote the passive change of the place. The term **“transport system”** includes transport modes and the facilities identified which are necessary for the change of place (transport). The urban transport system is classified into two types, **passenger** and **commercial transport**. The passenger transport includes **individual transport modes** (walking, bicycle, car and two-wheelers) and **public transport modes** (Bus, light rail and Para-transit). Similarly, the commercial transport includes **service transport modes** (Van, Car and tri-cycle) and **freight transport modes** (bicycle, motorcycle, rail, truck, animal and hand cart).

3.3 Objectives and Mechanisms of Traffic Management

The requirements on the traffic management and transport development are increasing from all levels including sustainability. In recent times, sustainability issues related to traffic management and transport development need to be addressed. In general, the concept of sustainability includes issues related to social, economic and ecological development state of the region. Traffic management and transport development are expected to promote the social stability and equity and simultaneously are expected to enhance the economic and ecological capabilities (conservation and protection of economic and environmental resources). However in actual practice, there are conflicts and trade-offs of many factors in the process to achieve a sustainable transport development. For example, the environmental and economic issues are inadequately addressed in several transport development projects. The current focus of transport development is limited to ensuring transport accessibility and mobility. Thus, in achieving a balance between the social, economic and ecological factors related to transport development, the conflicts created present possibilities for the implementation of traffic management. While the expectations of traffic management are enhancing the mobility, safety and economy of transport without being detrimental to the built-up and the natural environment, the sustainability issues are also adequately addressed. Furthermore, traffic management employs non-construction methods, techniques and strategies to increase the efficiency of the existing transport systems. This adopted approach by traffic management reduces the use of economic, ecological and social resources. Therefore, traffic management bears a high potential to promote the sustainable transport development and to fulfil the sustainable transport objectives.

Based on the given aim of traffic management, the objectives of traffic management can be classified as either operative or strategic objectives. The operative objectives of traffic management are focused on creating three influences:

- **to avoid traffic**,
- **to shift traffic**, and
- **to control traffic**.

The influences shall achieve equilibrium between traffic demand and transport supply. The above given traffic management operative objectives are differentiated by long-term, medium-term, and short-term planning duration (Figure 3-1).

Avoiding traffic is a long-term operative objective, which includes traffic avoidance by linking, substituting, and modifying trips in long-term planning approach (5-10 years). The mechanisms of linking trips are applied to reduce the number of trips and their trips lengths (vehicle-km or passenger-km). Some examples of modifying trips are trip chaining and multi-purpose trips. Another mechanism involved for avoiding trips is the trip substitution by technology. In this case, the trips are reduced by substituting a trip to other non-commuting forms such as teleworking and teleconferencing. Modifying trips is another mechanism to avoid trips in which trips (e.g. shopping trips) are modified by other trip types (household delivery trips). The mechanisms of modifying trips are applied in cases where multiple trips have common origins or destinations (O/D's). The trips are also reduced by means of changing settlement structures or by reducing trip distances. The future mechanisms that avoid traffic will involve land-use planning, road-pricing (tolled highways, increased road taxes) and economic disincentives (increased fuel rates).

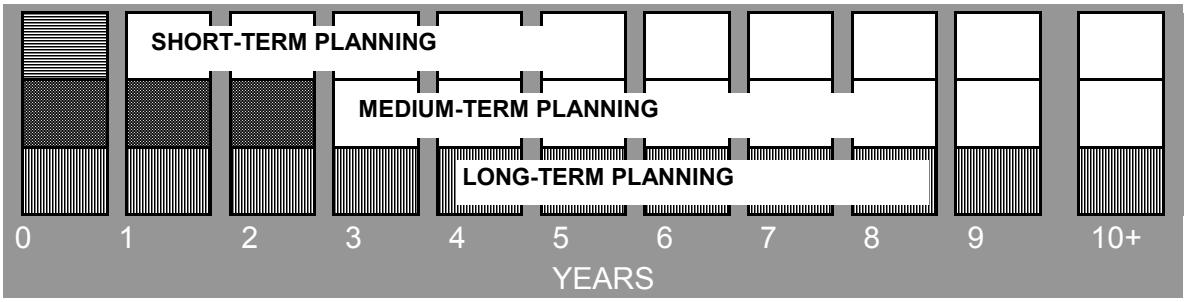


Figure 3-1: Time scale of planning

Shifting traffic is another operative objective which includes shifting traffic among different times, modes and destinations (routes and locations) in all-terms (short, medium and long term) planning approaches (1-10 years). The mechanism of shifting traffic to other modes includes shifting to high-capacity public transport modes and non-motorised transport modes. Another mechanism to shift traffic is to shift trip destinations close to trip origins (traffic-demand origins). Through this mechanism, the average trip lengths are reduced. Another mechanism of shifting traffic involves shifting traffic at different times. This mechanism reduces the peak period traffic, reduction in trip times and trip lengths.

Controlling traffic is a short-term operative objective, which includes controlling the network, transport modes and transport users in short-term planning approach (0-1 years). Therefore, the mechanisms used for controlling traffic are the most dynamic forms of traffic management applications in which mostly the transport capacity is dynamically optimised for meeting existing traffic demand (e.g. Radio message on bad weather conditions influences traffic demand).

The operative objectives and mechanisms of traffic management are explained in Table 3-1 with examples and prerequisites the application of traffic management measures. The operative objectives are basic objectives for the fulfilment of aim of the traffic management (to balance transport supply with traffic demand) formulated by policy planners and traffic managers. The strategic objectives of traffic management are objectives that are formulated based on defined strategies of traffic management for a specific **traffic management situation**. The TM situation could be described by the prevailing traffic and transport problems, poor transport development state and the poor transport performance. The strategies objectives are based on **TM influence area**, **TM influence types** and **TM influence mechanisms (modules)**. The **TM influence area** of a strategic objective depends on the influence either on traffic demand or on transport supply. Where the **TM influence area** pertaining to traffic demand is aimed at the reduction of overall traffic demand by using mechanisms of linking trips, substituting trips, modifying trips, and shifting trips (to alternate times, modes and destinations); the influence area pertaining to transport supply is aimed at augmenting the transport supply by controlling the transport network, transport modes and transport users. **TM Influence types** form the basis of the formulation of strategic objectives and subsequently the basis of the formulation of traffic management strategies which will be explained in the later chapters. **A traffic management module is an established traffic influencing process or a mechanism for the implementation of measures**. Following the definition of TM module, **a traffic management measure is a desired realisation of an action that creates traffic influences towards the desired improvement of a defined transport situation**.

A traffic management strategy is defined as a pre-defined action plan for the implementation of TM measures to improve the transport situation.

These influence types propose the application of TM modules as the instruments of traffic management for their fulfilment. The study on Congestion-free Hessen selected eleven traffic management influence types based on two influence areas (Staufreies Hessen, 2015).

Operative Objectives	Mechanisms	Examples	Pre-requisites
to avoid traffic	• **linking trips**	Trip chaining & multipurpose tours	Development of program
	• **substituting trips**	Trip reduction ordinances, special traffic regulations	Establishment of laws and regulations
	• **modifying trips**	Household deliveries	Establishment of home delivery system
to shift traffic	• **alternate times**	City logistics system	Establishment of city logistics system
	• **alternate modes**	Inter-operable transport	Interoperability of transport preparedness
	• **alternate destinations**	Diversion routes, evacuation routes	Development of diversion and evacuation plans
to control traffic	• **network**	Signalised traffic control	Development of signal timing plan
	• **transport modes**	Vehicle improvement (tyre chains, reflector devices etc.)	Set up automobile repair centres
	• **transport user**	Disaster and traffic related information	Establish disaster and traffic information service

Note: Modified and recreated from Strickland and Berman, 1992

Table 3-1: Traffic management operative objectives and mechanisms

The eleven TM influence types are explained in later sections. Six of the influence types belong to traffic demand and five of the influence types belong to transport supply (see Table 3-2):

- **Total traffic demand:** In this influence type, TM influences the need to travel and automobile-travel demand in general and thus reduces the overall traffic demand.
- **Vehicle utilisation:** In this influence type, TM influences the vehicle utilisation by increasing the vehicle occupancies of all modes and thus reduces the total trips by different modes.
- **Mode selection:** In this influence type, TM influences the selection of transport modes to reduce to total number of vehicle trips (vehicle-km).
- **Destination selection:** In this influence type, TM influences the selection of a destination and thus reduces the traffic demand for given destinations by diverting the trips to other destinations.
- **Route selection:** In this influence type, TM influences the selection of a transport route and thus reduces the traffic demand for a given route by diverting the trips to other transport routes.
- **Time selection:** In this influence type, TM influences the selection of time for performing a trip and thus reduces the peak-period traffic volume.
- **Transport capacity and supply adaptation:** In this influence type, TM influences the transport capacity and other transport supplies, and thus augments the transport supply by either adding new transport supplies or optimising the existing transport supplies.

- **Traffic accidents:** In this influence type, TM influences the traffic accident-related problems (traffic-flow related) and thus augments the transport supply by traffic education and traffic incident management.
- **Long-duration traffic influencing activities:** In this influence type, TM influences the already existing management systems for improving the traffic-flow conditions at permanent work-zones or traffic incident-zones (long-term).
- **Short-duration traffic influencing activities:** In this influence type, TM influences the already existing management systems for improving the traffic-flow conditions at temporary work-zones (roadway maintenance, winter management) or traffic incident-zones (short-term).
- **Disturbances of traffic flow:** In this influence type, TM influences the transport supply for all disturbances of traffic flow which originate from other than accidents, incidents and work-zones. These disturbances include but are not confined to sudden braking, sudden change in traffic flow conditions due to poor visibility, rain, snow, black-ice, etc.

The given TM influence types indicate that the approach of traffic management cannot be limited to transport supply-augmentation measures and traffic demand-reduction measures are equally required to satisfy the objectives of traffic management.

3.4 Traffic Management Modules

The application of TM measures needs the use of various political, technical and economic resources. In practice, the stakeholders of the transport sector (transport planners and traffic managers) identify the specific requirements for the implementation of TM measures based both on the previous experiences and on technical research. The knowledge of specific requirements makes the planning and implementation of TM measures easier by proper selection of resources, selection of processes and mechanisms, and identification of potential stakeholders of traffic management.

A total of twelve traffic management modules are identified and selected based on the literature on traffic management. Traffic management modules are instruments for the implementation of traffic management measures. The Table 3-3 provides the distribution and allocation of TM measures in twelve TM modules. The figure gives an example of the use of relevant TM modules and measures in disaster situations only. These modules also present the involvement of potential stakeholders for the TM problem-solving process. The following sections provide a brief description of TM modules applicable to disaster management.

- **Political and Administrative Framework:** This module refers to the TM measures applicable for both pre-disaster and post-disaster traffic management. The political and administrative framework is a pre-requisite for the application of most traffic management measures. This module is an inter-disciplinary module and includes most of the TM measures which require legal, political and administrative framework for their application. The TM measures that involve political and administrative intervention usually expect strict enforcement of measures and are cost-intensive measures. Therefore the involvement of legal, political and administrative institutions is necessary for measures involving huge subsidies and strict law enforcement.

- **Land-Use Zoning Regulations:** This module refers to the change of the existing land use in order to make the optimal use of deficient transport infrastructure. The module also includes shifting the major traffic origin and destination centres (activity centres) to reduce the trip lengths.

TM Influence Area	TM Influence Types		Possible TM Modules
Traffic Demand	D1	Total Traffic Demand	• Political and administrative framework
			• Land use zoning regulations
			• Capacity Utilisation of all Transport Modes
			• Non-Motorised Transport Improvement
			• Public Transport Improvement
			• Traffic & Disaster Information Management
	D2	Vehicle Utilisation	• Capacity Utilisation of IMT Modes
			• Capacity Utilisation of PT Modes
			• Road Pricing
			• Freight Transport Improvement
	D3	Mode Selection	• Traffic Education and Public Awareness
			• Traffic & Disaster Information Management
			• Non-Motorised Transport Improvement
			• Public Transport Improvement
	D4	Destination Selection	• Political and administrative framework
			• Land use zoning regulations
			• Road Pricing
			• Traffic Education and Public Awareness
	D5	Route Selection	• Political and administrative framework
			• Land use zoning regulations
			• Road Pricing
			• Traffic & Disaster Information Management
	D6	Time Selection	• Traffic Education and Public Awareness
			• Traffic & Disaster Information Management
			• Freight Transport Improvement
Transport Supply	S1	Transport Capacity & Supply Adaptation	• Political and administrative framework
			• Capacity Utilisation of Transport Modes
			• Traffic & Disaster Information Management
			• Inter-Urban & Urban Traffic Control
	S2	Traffic Accidents	• Traffic Education and Public Awareness
			• Traffic & Disaster Information Management
			• Traffic Incident Management
	S3	Long Duration Activities	• Political and administrative framework
			• Land use zoning regulations
			• Traffic & Disaster Information Management
			• Non-Motorised Transport Improvement
			• Work-Zone Management
	S4	Short Duration Activities	• Traffic Education and Public Awareness
			• Traffic & Disaster Information Management
			• Inter-Urban & Urban Traffic Control
			• Work-Zone Management
	S5	Disturbances to Traffic flow	• Freight Transport Improvement
			• Traffic Incident Management
			• Work-Zone Management

Table 3-2: TM influence types and TM modules

- **Capacity Utilisation of Transport Modes:** This module refers to the full utilisation of available capacity for all transport modes. In IMT, this module is used to improve the occupancy of single-occupancy vehicles. In PT, this module uses the principles of integrated time scheduling (fixed-time transfer) to maximise connections with other transport modes. Furthermore, this module suggests the use of high-capacity modes of PT which increases the capacity without increasing the vehicle fleet. In FT, this module recommends the better coordination with freight operators to maximise the freight capacity utilisation. In MIM transport, this module suggests the inter-operability of transport modes to minimise trips (both passenger and freight trips) by using unutilised capacity of several modes.

- **Road Pricing:** Road pricing is a controversial issue in disaster traffic management due to its reported negative impacts on mobility by some traffic experts. This module refers to reducing the unnecessary mobility by differentiated charging of the use of transport facilities and services. The groups targeted for the trip reduction are commercial unorganised media, disaster tourists and unorganised research organisations.
- **Traffic Education and Public Awareness:** This module is necessary for the implementation and success of several TM measures which require adequate traffic education and public awareness. Adequate traffic education and training is critical to TM measures which especially deal with implementation of new traffic rules and regulations for disaster situations.
- **Traffic & Disaster Information Management:** This module refers to the establishment of organisation and operation of both disaster traffic management centre (DTMC) and traffic and disaster information service. The module covers most traffic information-related aspects during disasters. The module recommends the establishment of traffic and disaster control centres and traffic monitoring stations. The various methods of traffic information collection, processing and dissemination are a part of this module.
- **Inter-Urban & Urban Traffic Control:** This module covers the traffic management for both urban areas and inter-urban areas. The measures that are a part of this module are road network control, road section control, improvement of signalised and the non-signalised traffic control (among others). The module prerequisites the availability of various types of traffic control and information devices.
- **Non-Motorised Transport Improvement:** This module refers to using the potential of NMT. In disasters, the infrastructure is deficient and the use of NMT modes wherever possible, is an effective option to improve mobility. This module patronises the use of NMT modes for short distances and suggests measures to support NMT.
- **Public Transport Improvement:** This module refers to the improvement of public transport to maximise the mobility of people during disasters. The improvement includes new rules of PT operations, new PT scheduling, minor modifications in the existing infrastructure and PT accessibility improvement among other measures.
- **Freight Transport Improvement:** This module addresses the potential to organise the freight transport processes for the purposes of effective distribution of goods. This module proposes the use of various freight coordination schemes and the establishment of freight complexes to optimise the distribution of goods. The conflicts between FT and other transport modes are minimised by measures focusing on reduction of IMT trips through home shopping network, improved parking facilities for FT and time slots for FT.
- **Traffic Incident Management:** This module recommends the application of the established concept of TIM for problems due to traffic incidents. This module supports and recommends the application of TM measures in every phase of traffic incident management to facilitate the process. The detection and verification of traffic incidents is supported by establishing traffic control and monitoring stations. Furthermore, the

provision of updated traffic and disaster information reduces the issues pertaining to detection and verification. Traffic signal control is a recommended measure during the response phase of TIM to reduce the response time to and from the incident site. Incident site management and incident clearance phase of TIM involves the measures such as road network control, improvement of non-signalised intersection control and establishment of work-zone coordination and management centre. Finally, the recovery from the impacts of traffic incidents are addressed by the implementation of road network control measures involving closures and diversions.

- **Work-Zone Management:** This module is selected in the list of modules due to the understated issue of traffic management during the disaster recovery. Disaster recovery involves a lot of activities related to construction, repair and maintenance. This module supports the activities at temporary and permanent work zones also called mobile and stationary work zones. In this module, the potential of the improvement of traffic flow by using work-zone management concepts is established for disasters involving multiple work zones. The benefits apart from reducing the long duration of disaster recovery are safety, economy and environmental benefits.

It is important to note here that creating a specific influence may need multiple traffic management modules. One example of TM influence is the mode selection, in which the traffic education and public awareness module recommends educating the potential road users for rationalising the use of transport modes. The TM module 'traffic and disaster information management' refers to providing pre-trip and en-route information to the passenger and IMT users to influence their travel decisions pertaining to the use of transport modes. Similarly the TM module 'non-motorised transport improvement' suggests the improvement of services and facilities required by NMT user. The module suggests measures that change the use of IMT, PT modes to NMT modes. In addition to the above, the TM module 'public transport improvement' recommends increasing the capacity of PT modes and providing necessary improvement measures such as PT network improvement, PT scheduling improvement and PT accessibility improvement in order to influence the decision of existing IMT users to use PT modes.

Table 3-3: Traffic management modules and measures

TM Modules	TM Measures				
Political and Administrative Framework	Economic or preferential incentives and disincentives	Trip reduction ordinances	Special disaster transport services	Special traffic rules enforcement	
	Economic or preferential incentives and disincentives for alternate mode use	Compulsory closing of public and private establishments	Inter-state transport operation (agreement necessary)	Vehicle improvement	
	Economic or preferential incentives and disincentives for alternate destinations	Alternative or flexible work schedules	Personalised Para-transit service (agreement necessary)	Speed limits	
	Economic or preferential incentives and disincentives for alternate routes	Certificate scheme	Automobile roadway repair service (agreement necessary)	Access restrictions	
	Economic or preferential incentives and disincentives for alternate times	Inter-operable transport	Car rental service (agreement necessary)	Overtaking restrictions	
		Procurement of company vehicles	Procurement of company vehicles (agreement necessary)	Parking restrictions	
		Trip chaining programs		HOV priority system	
				Disaster traffic priority system	
Land-Use Zoning Regulations	Land-use modification ordinances				
	Temporary land-use zoning				
	Shifting activity centres				
Capacity Utilisation of Transport Modes	Car pooling and other ride sharing programs	Public transport scheduling improvement	City logistics system	Trip reduction ordinances	Public transport capacity improvement
	Park and Share schemes	Multimodal integrated time scheduling (Integraler taktfahrplan)	Freight transport coordination schemes	Inter-operable transport	Use of double decker buses
	Car pooling schemes		Freight distribution centres	Change the use of public transport to freight transport	Use of trolley units for public transit vehicles
	Car sharing schemes			Change the use of service transport to public transport	
Road Pricing	Economic or preferential incentives and disincentives				
	Certificate scheme				
Traffic Education and Public Awareness	Trip reduction ordinances	Special traffic rules enforcement	Disaster traffic priority system	Disaster training and exercises	
	Compulsory closing of public and private establishments	Vehicle improvement	Triage based traffic priority	Emergeny responder training and exercises	
	Alternative or flexible work schedules	Automobile repair stations	Certificate scheme	Civilian training and exercises	
	Trip chaining and multi-purpose tours promotion	Access, overtaking and parking restrictions	HOV priority rules		
Traffic and Disaster Information Management	Disaster traffic management Centre	Traffic and disaster information service			
	On-site traffic control centre	Pre-trip information	En-route information		
	Traffic control sub-centres	Internet	Wireless		
	Traffic monitoring stations	Wireless	Commercial radio and television		
	Weather monitoring stations	Commercial radio and television	Traffic message channel		
		Traffic message channel	In-vehicle information systems		
		Information kiosks	Dynamic message signs		
		Roadside public terminals			
		Local newspapers			
Inter-Urban and Urban Traffic Control	Road network control	Road section control	Improvement of signalised traffic control	Improvement of non-signalised traffic control	Improvement of inter-modal and parking facilities
	Access restriction and control	Lane management and control	Traffic signal prioritisation	Traffic signs	Parking management
	Road closures	Reversible flow lanes	- Emergency vehicles priority	Static Signs	Parking restrictions
	Automobile restricted zones	Turning movement restrictions	- Public transport priority	Dynamic message signs	Parking lot closures
	Ramp closures	Overturning restrictions	-HOV priority	- Accident and congestion warning signs	Parking guidance
	One-way streets	Variable speed limits	Traffic signal control and coordination	-variable speed limits	Priority parking
	Closing side streets	Lane closures	-Traffic gating	-weather information	Parking information
	Establishment of diversion routes	Use of shoulder lanes	-Green wave coordination	Static and dynamic road markings	Establishment of freight parking zones
	Contra flow roads	High occupancy vehicle lanes	-Modification of signal phase timing	Static road markings	Free or subsidised parking
	Diversion routes	Bus lanes		Dynamic road markings	
	Ramp metering and control	Goods vehicle-only lanes		Miscellaneous traffic control devices	
	Ramp metering	Speed zoning and management		Central refuge	
	Ramp closures	Variable speed limits		Lighted traffic bollards	
	Priority access	Static Signs		Visibility enhancement devices	
		Dynamic message signs			
Non-Motorised Transport Improvement	Establishment of pedestrian routes and facilities	Establishment of bicycle routes and facilities			
	Pedestrian escape routes	Bicycle escape routes			
	Pedestrian routes to public transit stations	Bicycle routes to public transit stations			
	Pedestrian stop facilities	Bicycle shelters			
Public Transport Improvement	Public transport network improvement	Public transport scheduling improvement	Public transport accessibility improvement	Public transport capacity improvement	Improvement of inter-modal and parking facilities
	Extension of fixed routes	Travel roster plans	Feeder services	Use of high capacity (double- decker) buses	Park and ride facilities
	Modification of fixed routes	Vehicle rotation plans	Pedestrian routes to public transit stations	Use of trolley units/coaches for public transit vehicles	Increased parking spaces
		Revised frequency plans	Bicycle routes to public transit stations		Free or subsided parking
		Integraler taktfahrplan			
Freight Transport Improvement	City logistics system	Household goods delivery transport system	Freight traffic operations control		
	Freight transport coordination schemes	Home shopping network	Freight transport entry time restriction		
	Freight distribution centres				
	Establishment of freight parking zones				
Traffic Incident Management	Traffic incident management system				
	Detection and Verification	Response	Site management	Clearance	Recovery
	Disaster traffic management centre	Improvement of signalised traffic control	Road network control	Work- zone coordination and management centre	Road network control
	On-site traffic control centre	Traffic signal prioritisation	Lane closures	Mobile work zones	Lane closures
	Traffic control sub-centres	- Emergency vehicles priority	Ramp closures	Shadow vehicle	Ramp closures
	Traffic monitoring stations	Traffic signal control and coordination	Contra flow roads	Truck mounted attenuator	Contra flow roads
	Weather monitoring stations	-Traffic gating	Diversion routes	Manual traffic control	Diversion routes
	Improvement of non-signalised traffic control	-Green wave coordination	Improvement of non-signalised traffic control	Automobile roadway repair service	Improvement of non-signalised traffic control
	Dynamic message signs	-Modification of signal phase timing	Dynamic road markings	Automobile roadway repair mechanics	Dynamic road markings
	- Accident and congestion warning signs		Visibility enhancement devices	Towing vehicles	Visibility enhancement devices
	-speed control		Work- zone coordination and management centre		Dynamic message signs
	-overturning restrictions		Stationary work zones		- Accident and congestion warning signs
	Traffic and disaster information service				-speed control
	In-vehicle traffic information and route guidance				-overturning restrictions
	-Traffic message channel				Mobile work zones
	-commercial radio and television				
	-telephone information systms				
Work Zone Management	Work- zone coordination and management centre				
	Stationary work zones	Mobile work zones			
	- Accident and congestion warning signs	Shadow vehicle			
	-variable speed limits	Truck mounted attenuator			
	Lane closures	Manual traffic control			
	Dynamic road markings				
	Manual traffic control				

Legend:

- Measures
- Sub-measures
- Sub-measure types

3.5 Classification by Transport Modes

S.No.	Classification & Title of measure	Investigated regions	
		Dresden	Nagapattinam
PT	**Public Transport Measures**		
1	Economic or Preferential Incentives for Public Transport	X	√
2	Public Transport Network Improvements	√	√
3	Public Transport Scheduling Improvements	√	√
4	Public Transport Accessibility Improvements	√	X
5	Personalisd Para-transit Services	X	X
6	Public Transport Right of Way Prioritisation	√	X
7	Disaster Traffic Priority Assignment	√	√
8	Disaster Transport Services	√	√
9	Public Transport Information Services	√	X
10	Public Transport Management Center	√	√
11	Inter-state Transport Operations	√	√
NMT	**Non-Motorised Transport Measures**		
1	Establishment of Footpaths & Facilities	X	X
2	Establishment of Bicycle lanes & Facilities	X	X
3	Establishment of Automobile restricted zones	√	?
IMT	**Individual Motorised Vehicle Measures**		
1	Carpooling and other Ride Sharing Programs	√	X
2	Car Rental Services	√	X
3	Fuel and Vehicle Taxes	X	X
4	Special Traffic Rules Enforcement	√	X
5	Vehicle Improvements	√	X
6	Automobile Roadway Repair Service	√	X
MIM	**Multimodal and Intermodal Transport Measures**		
1	Road Network Control (Diversion Routes establishment)	√	√
2	Road Network Control(Access and parking Restrictions)	√	√
3	Road Section Control (HOV Lanes Establishment)	√	√
4	Road Section Control(Speed Management)	√	X
5	Park & Ride Facilities	√	X
6	Park and Share Facilities	√	X
7	Alternate Trip Schedules & Trip substitutions	√	X
8	Interoperable & Multi-functionalTransport	X	√
9	Multimodal Integrated Time Scheduling/Connection Matching	X	√
10	Trip Chaining/Multipurpose Tours	?	?
11	HOV Economic or Preferential Incentives	X	X
12	Improvement of Junction Control	√	X
13	Improvement of Traffic Signal Control	√	X
14	Land use ordinances	X	√
15	Traffic & Disaster Information Updates	X	√
16	Work Zone Coordination & Management Centre	X	√
FR	**Freight Transport Measures**		
1	City Logistics System	X	X
2	Household Goods Delivery Transportation System	X	X
3	Freight Traffic Operations Control	X	X

Note:
√ = Implemented or observed
? = Unknown
X = Partially or not implemented

Table 3-4: Traffic management measures classification (Transport Modes)

The traffic management measures can be classified based on addressed transport modes. The Table 3-4 provides the TM measures applied in disasters in two cities, one a European city and an Indian city. The TM measures are classified based on five transport modes (PT, NMT, IMT, MIM and FT). The following section provides the characteristics of measures based on transport modes.

In general, public transport has three main functionalities, which are related to commercial, substitution and social functionalities. The **commercial functionality** is primarily important to the public transport systems operator to maximise the revenues. This functionality can be expressed by maximising the number of passenger served. The **substitution functionality** is generally meant to shift the use of IMT modes to PT modes. This functionality is expressed by minimising the car-based trips and the subsequent reduction in the associated problems of congestion, accidents and environmental pollution. The **social functionality** is meant to fulfil the social responsibility of public transport in providing adequate and affordable PT services to the people. Therefore the social functionality may be expressed as "everyone must have access to the public transport system" (Gercek, Karpak et al., 2004).

- **Public transport measures** are aimed at patronising the use of public transport and its associated services. The implementation of public transport measures are advocated in urban situations which experience a high use of IMT modes and a heterogeneous traffic flow conditions.
- **Non-motorised transport measures** are aimed at the provision of adequate right-of-way for such non-motorised transport modes as bicycles and pedestrians. The NMT measures include the provision of adequate facilities and the safe environment for the operations of both pedestrian and bicycle traffic. Such measures are implemented to harness the potential of cycling and walking to limit the use of individual motorised transport modes for short trips.
- **Individual motorised transport measures** are aimed at improving the traffic flow conditions and efficiency of IMT modes. Thus, the IMT measures improve traffic safety, transport economy and transport environment.
- **Inter-modal transport measures** are aimed at the provision and organisation of inter-modal facilities especially the parking and transfer points for the purpose of promoting the use of high capacity or high occupancy transport modes (PT and IMT).
- **Multi-modal transport measures** are aimed at the improvement of the traffic flow conditions by the multiple modes by a single application of measure. This category includes measures such as application of green-wave for all road transport modes and pre-emption of traffic using traffic signal control.
- **Freight Transport Measures** are mostly aimed at minimising the conflicts between FT and other modes. This category also involves the use of available capacities of FT modes by coordinating different FT operators. In addition, the measures that reduce the environmental impacts of freight transport are also covered in this category.

Another classification is based on the categories of requirements of resources for TM measures (Table 3-5). The resultant categories of TM measures are: **(i) administrative and organisational measures**, **(ii) economic measures**, **(iii) technical and operational measures** and, **(iv) information measures**. Four examples of such classification of measures are given in the next chapter in four phases of disaster management. In general, the administrative and organisational measures are focused on ensuring the enforcement of laws and regulation. This category includes organisational measures that improve the public acceptance and institutional participation. The economic measures are focused on providing economic incentives or disincentives to control the

uses of particular transport modes. The technical and operational measures are focused on implementing appropriate traffic control or traffic information dissemination to influence the traffic flow, road user or traffic and transport processes. This category includes traffic engineering measures. Information measures are focused on changing the travel decisions of road users such as time of travel, mode of travel, route of travel, destination of travel and travel speeds through the dissemination of pre-trip or on-trip traffic information.

Traffic Management Measures
Administrative and organisational measures ➨ Legal measures (Strict enforcement of building codes, special design codes) ➨ Political measures (Inter-state or international agreements) ➨ Planning measures (Evacuation plans, contigency plans, circulation plans) ➨ Organisational measures (Public participation, traffic management centre)
Economic measures ➨ Economic or preferential incentives and disincentives for a particular transport mode use (High occupancy vehicle parking fees) ➨ Economic incentives and disincentives for alternate travel time and congestion pricing (Free travel during certain times)
Technical and operational measures ➨ Signalisation ➨ Patrols ➨ Surveillance ➨ Geometric modifications (temporary lane closures, reversible lanes, and temporary contra flow and moveable barriers) ➨ Operational measures (prioritisation, scheduling, speed reductions, manned traffic control)
Informational measures ➨ In-vehicle collective information and route guidance (Highway advisory radio) ➨ In-vehicle individual information and route guidance (Navigation systems) ➨ Roadside collective information and route guidance (VMS) and ➨ Roadside and other individual information (interactive information terminal, internet)

Table 3-5: Traffic management measures classification (Resources)

3.6 Expectations and Pre-requisites of Traffic Management

The effectiveness of TM measures is expected in the fulfilment of desired aims and objectives of traffic management. Another expectation of TM measures is the desired applicability of measures which includes:

- **cost of measure**,
- **technical systems**,
- **institutional participation**, and
- **public acceptance**.

While selecting TM measures, the other criteria such as clearly defined and desired quality, quantity (number of resources), availability of resources (within and outside the traffic management area) and the time frames (start and end times of TM measures) are also considered.

Traffic management resources are the unprocessed elements of time, money, equipment and machinery, facilities, manpower and expertise, and other similar elements that are used to fulfil traffic management objectives and plans. **Traffic management objectives** refer to specific targets towards the achievement of a goal. The **targets** ensure the reduction of vagueness and enhance the precision to goal achievement. **TM goals** are often established by TM stakeholders and

provide a basic sense of direction for the measures. In order to fulfil the goals and objectives of traffic management, it is necessary to prepare an inventory of resources required and processes involved. This section provides the basic pre-requisites of traffic management. These prerequisites are:

- **Social and organisational pre-requisites:** Institutional participation and coordination plays an important role in the success of TM measures. In practice, the low participation and poor coordination among stakeholders of traffic management are due to lack of motivation, lack of organisational structure and conflicts of interests. The traffic management techniques employed for the measure should win the confidence of transport user groups and other concerned groups by enhancing the credibility of the administration and information to the involved users. A proper understanding of the expected benefits to the involved users (transport and concerned groups) is required by the traffic managers. The expectations of public acceptance and institutional participation are possible with efficient social and institutional development state in the traffic management application area with least disabilities (physical, educational and personal disabilities). Traffic management stakeholders need to be trained, educated and empowered to work under any organisational structure in cases of major disasters or traffic incidents. Therefore, it is necessary to anticipate the participation and coordination for TM measures and to provide suitable complimentary traffic management or other measures to overcome them.
- **Technological pre-requisites:** Traffic management involves several technical and operational devices for traffic information dissemination and traffic control. The availability and type of application of technical resources for traffic management depends on the technological development state of transport infrastructure, traffic control technology and vehicle technology. Traffic control and information systems are the basic requirements for the implementation of the TM measures. The application of Intelligent transport systems (ITS) are also considered a part of traffic management, although, the fact that the same impact can be created without the application of cost-intensive ITS is also true. Conversely, traffic management needs to be adaptable to traditional technologies in case of failure of existing information and control systems. Some examples to indicate the use of traditional information systems are the use of landlines, dial-up modems, print media, television, battery operated radios and text messaging services. The “Manual for Planning and Deployment of ITS in German Cities and Counties” provides various information and control systems for the purposes of traffic management (see Figure 3-2).

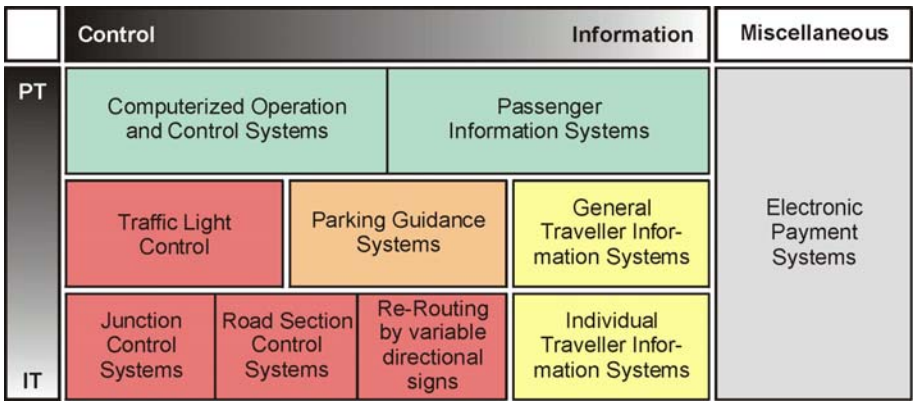


Figure 3-2: Illustration of traffic management systems (Boltze, Schaefer et al, 2005)

- **Economic pre-requisites:** The cost of implementing a measure is an important criterion for the selection and implementation of TM measures. Many measures that satisfy other criteria of effectiveness may not be selected due to the high costs of their implementation. Financial resources are required for necessary infrastructure, operations and organisational needs of TM measures. Especially in disasters, the economic state of people, State and the Nation is crucial to the success of TM goals and objectives. Some TM measures require vast subsidies from the government (procurement and operation of infrastructure and services) which are only possible with effective cash flows. One approach to minimise the cost of implementation of a TM measure is the use of locally available resources owing to the ease of availability, effectiveness of operations and ease of applicability to local conditions.
- **Legal pre-requisites:** Often demand-side and supply-side TM measures require special laws and enforcement in a mandatory form of restrictions, bans, mandatory guidelines and regulations. The unavailability of a legal framework of TM application causes ineffective traffic management. The legal framework should focus on laws and regulations on transport planning and traffic management, design of traffic management systems, supporting TM construction, and standard operating procedures (SOP's) for transport infrastructures and services. Literature reveals the limited application of existing traffic laws and regulations in disasters. Therefore there is a need to formulate a disaster transport policy. The inclusion of traffic management in the mainstream of disaster management will assist in the adequate recognition and legal application of traffic management.

3.7 Stakeholders of Traffic Management

Traffic management involves multiple transport agencies at central, state, regional and local levels. The goals and tasks of stakeholders vary among stakeholder based on their viewpoint. Accordingly, both the expectations and the conflicts vary. This section provides the role and responsibilities of TM stakeholders.

Land authorities

The governmental organisations at different levels (national, state, regional and local levels) are responsible for implementing or assisting in the application of different traffic management measures for improving traffic conditions of various transport modes. Often there are differences in

application of TM measures at national, state and local levels. The Centre and States are responsible for the operations and maintenance of the transport corridors and the associated traffic systems within their jurisdictions (e.g. National or State Highways). However the application of traffic management measures should conform to the uniformity-in-application of TM measures at all levels. The uniformity of application increases both the effectiveness and applicability of TM measures.

Although most objectives of TM supports social objectives (quality of life, economy, environment), there are conflicting arguments about the application of TM to support a specific research, technology, competition and employment. At local levels, the cities and councils are clients of public transport operators. In some European cities, the cities and councils work as regulators of public transport by setting a framework of integration and operation in public transport.

Public transport operators

Normally the operation of public transport service in many cities is either partially or completely organised through private operators (Bus, Train and Taxi operator). The public transport operators also provide information to the passengers (online and off-line information) by operating traffic information centres. The public transport scheduling, sequencing and operations are regulated by the concerned State or City Transport authorities. For example, a pre-empted signal control for public transport priority is regulated either independently or by the regulator.

However there are conflicts between public transport operators due to common interests of high revenue and popularity among PT users. Most public transport operators influence the choice of PT users by offering enhanced services (flat rate, student tickets, job ticket). This phenomenon leads to high competition and the lack of coordination among PT operators. An effective coordination is crucial to most PT operations in order to maximise the synergies by connecting two or more PT modes.

Service providers

The role of the service provider is to sell products and services that are accepted by the transport users and operators. These product and services could be basis or advanced requirements of transport users in fulfilling their mobility needs for example the use of highway advisory radio service or navigation systems for disseminating dynamic traffic information. Automobile roadway repair services such as ADAC in Germany offers service to their members (Car-Users) in cases of traffic incidents especially for towing and recovering of vehicles. These services are based on marketing concepts and the client requirements of added convenience.

The services offered by the mobility centres are differentiated. These services are either oriented by the market requirements or motivated by the transport politics. In the later case, they are subsidised by the government to promote the use of a particular transport. Mobility centres could also be operated internally by many organisations which regulate and control the traffic at work places and construction sites. In such cases, the costs involved in the operation of mobility centres is paid by the companies and the companies benefit through efficient services to their customers and people. The services offered by the non-commercial service provider may often pose difficulties to commercial providers in maintaining their status in the market. However, the ideas to develop and enhance the services generally originate from the commercial providers because they are constantly interested and engaged in providing enhanced and user-friendly products and services.

Manufacturers/Industries

Manufacturers and distributors of traffic and transport devices, and their applications follow a primary interest to sell their products. Due to the fact that the success of the manufacturer's product finally depends on customer benefits; they do have a strong interest in designing their products towards fulfilling the needs of end-users of traffic management devices. One classical example of such interest is the automobile industry. The car industry tries to improve customer benefits by exploiting traffic management principles for the design and operation of their products. The improved product design and operation, plus effective product marketing collectively impart attractiveness of their products to their costumers. Successful manufactures aim for high revenues and further promote the use of IMT modes. There are arguments to neglect the benefits of using such products for service-equivalent traffic management. This is due to the direct and surrogate marketing of their products which further promote the use of IMT modes.

Transport user groups

Transport users are participants who either profit or afflict from the application and implementation of TM measures directly. This group includes the transport users who use individual facilities and services for their respective transport modes. The advantages and disadvantages to the transport users are mostly related to enhancement of mobility and accessibility, the safety and economy of their transport. Transport environment is rarely considered by the transport user as a benefit due to the high costs incurred to the user for efficient fuel and technology. This group include IMT drivers, pedestrian, cyclists, PT users and FT users.

Further concerned groups

The concerned groups represent those who do not profit and afflict from the application of TM measures directly. The group includes residents, automobile and parts manufacturers, and the service operator groups. The public acceptance of non-transport users is very critical for the successful application of most TM measures.

Residents of urban areas where TM measures are implemented consider the degradation of their living quality through the secondary negative impacts of TM measures. These negative impacts are citied as increased air and noise pollution, and decreased accessibility and mobility of residents and other affected people. There is thus a need to adequately consider the negative impacts to the concerned groups. This endeavour will not only increase the effectiveness but also the application through enhanced public acceptance and institutional participation.

The changes in the principles of TM applications prerequisites modifications of traffic control information and other devices. The modifications required for the purpose affects the design and implementation of TM devices. Such modifications can also affect the production and consumption mechanisms of transport services. In cases where such changes become a norm, the manufacturing industry is affected. Furthermore there is academic discussion that the introduction and use of individual telematic services (automobile parts) will lead to a social disparity between traffic users.

The sustainable goals and objectives set by the traffic management authorities might pose challenges to service operators related to fulfilment of contracts, operation security, economic efficiency of operation and transport user acceptance.

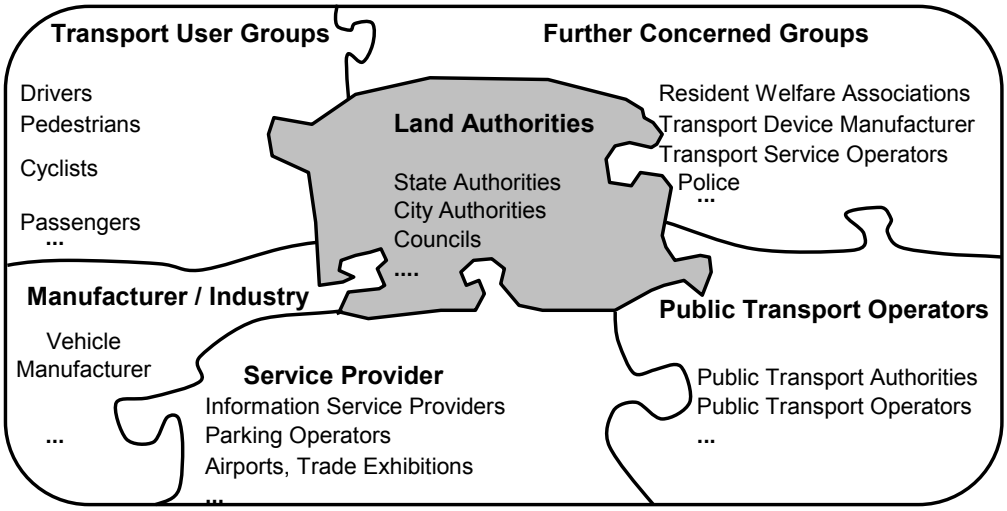


Figure 3-3: Stakeholders of traffic management (FGSV, 2003)

3.8 Conflicts and Risks of Traffic Management

The application of TM measures in the local environment does not always presents a win-win situation. The mobility needs of the society require planned efforts to achieve maximum benefits without interfering the functioning of other systems or processes. Often traffic managers operate the urban traffic and transport system under set goals and objectives. These set goals are:

- **To provide adequate accessibility and mobility**
- **To minimise the accidents**
- **To minimise the environmental impacts of transport**
- **To minimise the transport costs both for transport users and transport operators**

The above stated goals of the traffic management system are ideal and often involve conflicts and risks among the stakeholders of traffic management. These conflicts and risks are due to the following factors, for example:

- Persistent differences in the formulated goals and objectives of several TM stakeholders
- Persistent differences in the estimation of impacts of TM measures (possible and actual TM measure impacts)
- Persistent counter-effective secondary impacts on the urban transport system
- Persistent incompatibility among several TM measures
- Problems of further applications

There are conflicts between TM stakeholders with regard to **formulated goals and objectives of traffic management**. The conflicts are clearly observable between private and public stakeholders of traffic management. The orientation of public organisations is towards incurring large societal benefits even with economic burden to the governments in providing economic incentives to the people. On the contrary, orientation of private organisations considers economic objectives (revenue generation) prior to social objectives (social responsibilities).

Conflicts are observed due to **differences in the estimations of effectiveness and applicability of TM measures**. These differences originate from the lack of understanding of the estimation of actual impacts. The impacts of TM measures (effectiveness and applicability) are either underestimated or overestimated. One classical example of such overestimation of TM measure is

the traffic demand-side measures in which tele-working, teleconferencing and flexible working times area proposed to reduce both total traffic demand and peak-hour traffic demand. Some experts claim their ineffectiveness in reducing the total traffic demand. Their claim is that the positive impacts of reduced trips are lost due to the generation of negative impacts of generation of additional trip. Whereas the impacts on the society and environment are often underestimated by other stakeholders where high costs are involved.

Counter-effective secondary impacts are unwanted impacts of TM measures which reduce the positive impacts and create negative impacts. Some examples are:

- A large number of trips diverted by the application of traffic guidance systems on particular corridors can increase the congestion on other corridors.
- The road users are informed but not guided to the recommended corridor in the event of possible congestion through the application of collective traffic information (RDS-TMC). This leads to an unwanted shift of traffic on secondary network due to problems of traffic guidance. Secondly the impact of collective traffic information leads to a major shift of traffic on to other corridors which then become congested.
- The enhancement of facilities and services for IMT modes indirectly promotes the use of IMT modes which is undesirable and competes with the patronage to PT modes. This phenomenon results in the reversal to use IMT modes from the use of PT modes.
- Optimal number of users is required to attain the benefits offered by a transport service; if the number exceeds an optimal number; the benefits of the services are lost.
- The provision and use of multi-modal transport facilities and services (park and ride facilities and other interchange points) often leads to reversal of PT trips partially to IMT trips.

Incompatible measures packages are often risks to the effectiveness and applicability of the TM measures. Some examples are:

- In cases of incompatible TM measures of a strategy, the complimentary measures are required to offset the negative impacts created by the primary impacts. These complimentary measures require additional costs and therefore the total cost of implementation is increased substantially.
- The negative impacts on IMT modes are created due to the application of PT measures such as public transport priority. Such impacts are congestion-related high costs, high air and noise pollution due to idling of other traffic (IMT and FT) at intersections.
- The application of a green-wave principle of traffic signal control gives priority to the traffic on one particular corridor and creates negative impacts on the other corridors.

The above explained conflicts and risks provide motivations to traffic management to search for opportunities of intelligent connections of traffic and transport systems and the use of their individual capacities for the maximum utilisation.

3.9 Traffic Management State of Development

The first part of this section is a brief description of the traffic management issues in Indian conditions. These issues are not particular to any city of India. The issues of traffic management in

India are grouped and described in four different issues, which are: (i) legal and administrative issues, (ii) technical and operational issues, (iii) economic issues and (iv) organisational issues.

In the second part of this section, brief introduction of principles, techniques and application of traffic management in Germany is provided.

Finally the comparisons are made between the two countries in the application of traffic management.

Traffic management in India

Legal and administrative issues

Literature and investigations reveal the availability of adequate traffic management laws and regulations for transport supply augmentation but lacks the legal framework of application for traffic demand reduction. The approved national urban transport policy of India formulated in the year 2006 does not propose or include demand-side traffic management measures. The Police are the first authority for the implementation of TM measures in most Indian cities. Traffic police personnel are often untrained or less trained for the tasks involved of traffic management.

Technical and operational issues

In most Indian cities, traffic management employs conventional forms of traffic information and control devices and applications. The use of traffic control systems is mostly confined to traffic signal control, and the manual traffic control is extensively applied to overcome the deficit (traffic police, traffic wardens, and NGO's). The uses of information systems to guide, regulate, and warn traffic is limited to static information systems. The dynamic information systems are not a feature of traffic management in India. The traffic control devices such as barricades, traffic cones, and reflective devices are widely used. Regulatory techniques such as implementation of one-way streets, reversible streets, closing streets and movement restrictions are largely implemented in conjunction with manual traffic control. Information dissemination is generally poor, and radio channels are the most common source of traffic-related information which lacks both in quality and in quantity (comprehensiveness) of information. Traffic segregation is mostly performed by using traffic control devices (mostly miscellaneous traffic control devices) and time segregation (different time of operations of modes).

Traffic management in India lacks dedicated traffic management centres, traffic collection points and weather monitoring stations.

Economic issues

Inadequate funds are the most common problem of traffic management in India. Traffic management requires establishing traffic management centres and traffic monitoring centres. The establishment of these centres involves the use of cost-intensive advanced technologies and devices. Significant research has been done in first-world countries on the use of traffic technology in traffic management. The devices and applications in traffic management based on foreign technology are both expensive and having limited access to Indian markets. Even with the constraints of financial resources, the traffic management is still a cheaper option available to the transport sector than the cost-intensive transport infrastructure development for Indian conditions.

Organisational issues

The organisation of traffic management in India is very poor in most Indian towns and especially metropolitan cities e.g. Mumbai, New Delhi, Kolkata and Chennai. This is partially due to poor organisation of the transport sector including the traffic management sector. The poor state of

organisation is observable from the poor coordination between state transport organisations and private transport operators. Traffic management in India lacks strict enforcement of traffic laws and regulations, for example the driver licensing authorities lack proper training and testing of commercial and private drivers. This poor organisation leads to poor driving skills and high rates of accidents. Another issue pertaining to organisation is the lack of organisational framework of traffic management which causes undefined roles and responsibilities.

Traffic management in Germany

Germany is one of the leading countries in the application of traffic management measures and formulation of TM strategies. In the same manner, the German transport industry leads in the design and manufacturing of traffic control devices such as static and dynamic signs, signals, and traffic control devices. German public-private cooperation policy reveals that the traffic regulations, legal and organisational framework and the provision of traffic data are established by public transport sector. The private transport sector focuses on manufacturing and production of traffic management-related equipments, collection of additional traffic data, and provision of transport services. The public-private cooperation is largely observable in compatibility of traffic management-related equipments and applications, agreements of cooperation, subsidies to transport operators and traffic data management.

The Federal Ministry of Transport, Building and Urban Affairs, has comprehensive programs towards transport infrastructure development and traffic management. The national transport development plan emphasises the construction of 1730 kilometres or new highways, widening of 2162 kilometres of existing highways and construction of 717 bypasses across the country by 2015. Germany has a well-developed system of highways comprising over 12000 kilometres of the total 231,581 km of roads across 16 states. A five-year programme for traffic control on highways emphasises on the following: (i) use of traffic control devices on more than 1200 km of highways, (ii) 2400 km of highways with diversion routes possibilities and (iii) 15 additional traffic control centres.

Road traffic management in Germany chiefly involves two influences which are **“Netzbeeinflussung”** and **“Streckenbeeinflussung”**. Traffic managers in Germany on inter-urban roads operate the traffic using these two main influences.

The term “**Netzbeeinflussung**” is used to express road network control in which the traffic is diverted to another part of road network using the traffic control and information devices. This influence is focused on optimal use of the existing network capacity and various operational strategies to temporarily increase the road capacities. Access restrictions are a common type of road network control. The trucks are often restricted to the rightmost lane across Germany (and some other European countries). Furthermore, access restrictions are imposed to segregate unwanted traffic in time, destinations and routes,

Similarly the term “**Streckenbeeinflussung**” is used for expressing road section control in which the traffic flow is improved on the existing road using the traffic control and information devices. This influence is focused on speed management (harmonisation), providing accident and weather related warnings, and providing dynamic information on traffic and environmental conditions. Overtaking restrictions are enforced under this type of influence. Queue warning systems have recently evolved in which congestion pictographs are displayed to reduce the secondary traffic incidents. Temporary shoulder use locally called ‘dynamische Seitenstreifen freigabe” is a traffic management measure employed in conjunction with speed harmonisation to improve capacity on

highways. In daily traffic management both principles are extensively used. Ramp metering is comparatively new in Germany in which ramp-meters are installed at the entrances of highways (autobahns) to stagger the entering traffic into the highway traffic. Earlier the static signs were placed at the signals to indicate the number of vehicle allowed to enter a highway. In recent years the dynamic signs are increasingly applied to allow information to road users on available routes in cases of congestion, congestion/accidents/incidents related information and lane use based on current traffic conditions.

Urban traffic control in Germany includes traffic signal control, parking management, work-zone management and the use of other traffic management techniques. Traffic signal control is chiefly used to: (i) optimise the cycle-lengths, (ii) to provide priority to public transport, disaster vehicles, and NMT, and (iii) to improve traffic flow conditions through the application of green-wave principles. Dynamic parking information and parking-guidance systems are common features of German transport systems. The work-zone management measures are applied to improve traffic flow on highways by influencing the timings of constructions. The application of reversible lanes, tidal-flow operations and other geometric modifications are made using state-of-the art traffic control devices to improve the traffic conditions for both inter-urban and urban traffic.

In order to influence the traffic, German traffic operators have a long history of providing traffic information. The highways in Germany are equipped with traffic systems such as inductive loop detectors, floating car, video cameras and other sensors that gather traffic data. A primary use of traffic data is the basis of traffic information dissemination to transport users and to manage the congestion on the network. Germany has set a national goal to adequately serve 80 percent of all trips on the inter-urban network by providing dynamic information by 2010 (Staufreies Hessen, 2006). On German highways, rotational prisms and dynamic message signs (DMS) are used.

In cases of traffic disturbances, operators at the traffic management centres deploy alternative route information through dynamic message signs. Dynamic rerouting is becoming a common feature of highway operations in Germany and standardisation of information content in DMS is practised to avoid ambiguity and ensure comprehension.

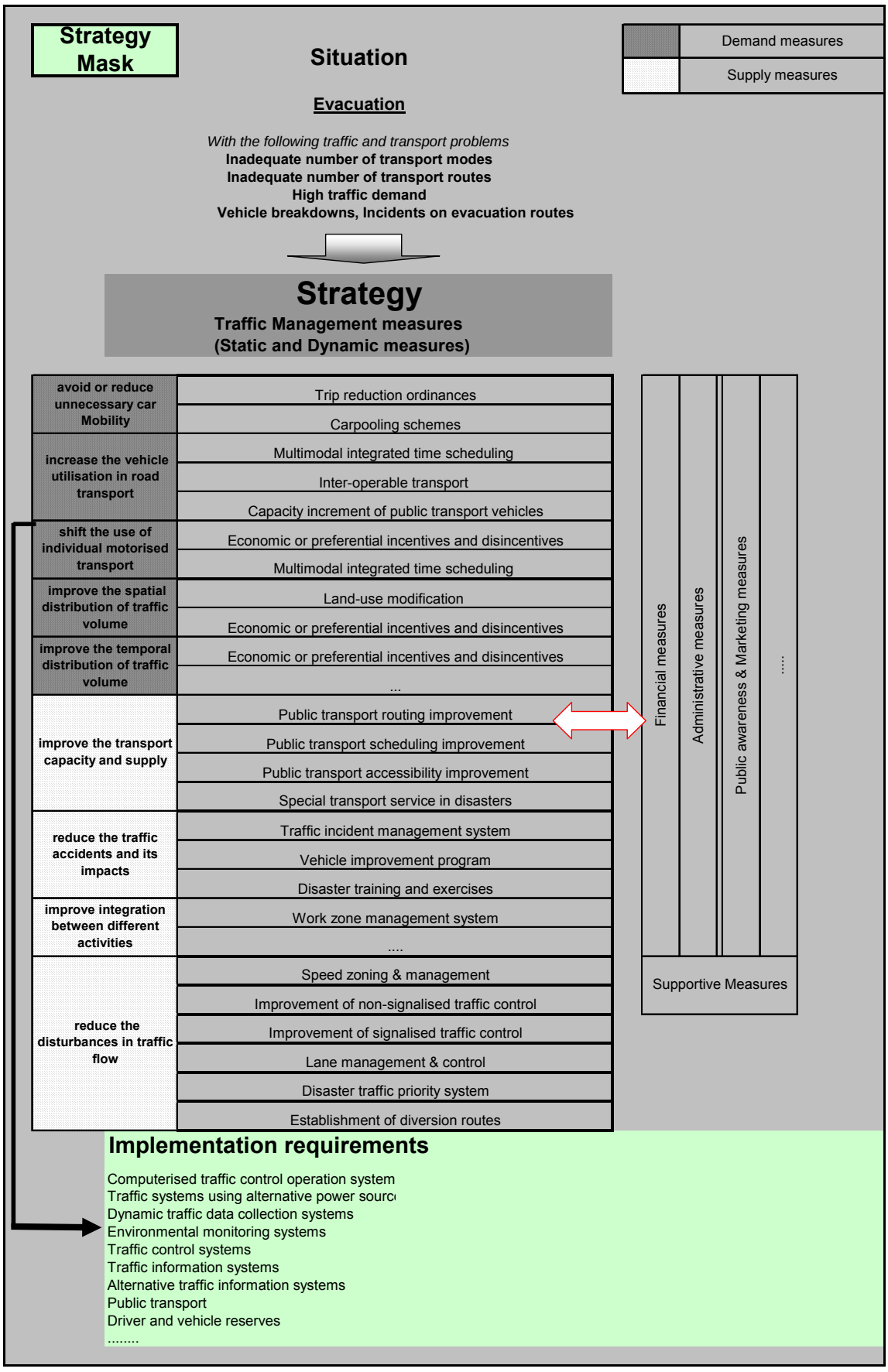
Radio Data System (RDS-TMC) is employed extensively to provide digitally encoded traffic messages which specify location and event codes for in-vehicle information systems. There are over fifty radio channels that support RDS-TMC transmissions in Germany.

In German traffic management, TM measures are rarely implemented as individual measures but a group of TM measures called TM strategies. The TM strategies are first formulated and later applied after estimating the effectiveness and applicability to various transport situations. A TM strategy consists of TM measures which are mutually supportive to each other and have no conflicts. “Staufreies Hessen 2015” (Congestion-Free Hessen) is a proactive approach of traffic management which provides the example of formulated strategies. The application of TM strategies is based on the strategy mask (see Figure 3-4). The strategy mask considers the transport situation and provides the strategies as a combination of different TM measures categorised by transport modes. A strategy mask also lists the implementation requirements for the application of measures and the supportive measures (also called complimentary measures). A similar approach has been adapted in this study for the formulation of TM strategies. In Figure 3-4, the strategy mask is illustrated for evacuation situations which provide both demand-side and supply side strategies.

A transport situation is a sum of three contributing factors which are: (i) traffic and transport problems, (ii) transport development state and (iii) transport performance. A combination of traffic

management strategies and transport situation provides a traffic management scenario. Various scenarios are analysed using modelling and simulation to the overall management of congestion in Germany. Like other European countries, Germany uses microscopic simulation software VISSIM to depict scenarios based on the transport situations and assess the impacts on the road network. The applications of such programs are calibrated to improve the software interfaces with the existing traffic control and other systems in Germany. Such applications are widely as valuable components in the decision- making process.

The success of the traffic management applications and strategies has contributed to its worldwide application including in the US, Australia and Asian cities like Singapore, Vietnam and Japan. The success of traffic management especially in transport-supply augmentation strategies in Germany is appreciable. Even with existing technologies and concepts, Germany faces challenges due to of fatal accidents, increasing rate of vehicle growth and increasing air and noise emissions. Such problems and issues cannot be solved through effective traffic control only. Therefore, there is a need to consider traffic-demand reduction strategies in conjunction with other given strategies in Germany too.



Note: Adapted from FGSV, 2003.

Figure 3-4: Example of a strategy mask for evacuation situation (FGSV, 2003)

Comparisons and Areas of Emphases

Some comparisons of traffic management applications categorised on different transport modes in Germany and India are given in Table 3-6. The comparisons reveal drastic differences in approach and applications of traffic management in these two countries. The current legal, technical, economic, and organisational issues in India are incomparable both in content and application with Germany. The traffic and transport issues in India provide both challenges and opportunities for the development of transport sector. There is an increasing application of traffic management in urban conglomerations in India recently. This phenomenon will allow the transfer of technologies, applications, and expertise from developed economies such as Germany to emerging economies such as India. This integration will allow India to access improved tools of transport planning and traffic management. Significant research is required especially in calibration of technologies and devices to provide suitable solutions for their application to Indian traffic conditions. The constraints of financial resources for TM will further insist governments and private investors to provide least-cost options. The following are areas of emphases for traffic management applications in India:

- **Road classification**: The road classification will permit effective maintenance and implementation of traffic management.
- **Vehicle classification**: The vehicle classification based on size, technology and modes will allow standardisations of vehicles and effective traffic control. Delhi has over 30 transport modes using the same road. The use of unauthorised vehicles (animal and hand carts) needs to be stopped immediately.
- **Effective laws and enforcement**: Correct enforcement requires changes in current laws and enforcement types. The Motor Vehicle Act, 1998 needs necessary amendments w.r.t. NMT modes and necessary accident investigations.
- **Traffic education and training**: Adequate traffic education and comprehensive driver training for respective categories of drivers is required before obtaining the licenses.
- **Standardised equipments and technologies**: Traffic control and information devices used in TM needs standardisation.
- **Chain of command**: Organisational framework describing all potential stakeholders with their roles and responsibilities is required. Enforcement agencies need to work in coordination.
- **Development of public transport**: Public transport needs PT planning (scheduling), PT management (information) and PT development (dedicated PT corridors) to solve most urban transport problems.
- **Development of non-motorised transport**: Adequate planning, management and development are required to harness the potential of NMT modes.

Table 3-6: Comparison of TM measures application in Germany and India

Measure Category	Description of measure	Application in Germany	Application in India
Public Transport Measures	Economic or Preferential Incentives for Public Transport	Partially subsidised	Largely subsidised
	Public Transport Network/Scheduling/Accessibility Improvements	Potential PT improvement options	Often ignores PT improvement options
	Public Transport Right of Way Prioritisation	Dedicated PTcorridors	No dedicated PT corridors
	Public Transport Information Services	Quality passenger information systems	Poor quality passenger information systems
	Public Transport Management Center	Established PTMC with dynamic control of PT operations	No established PTMC and static control of PT operations
Non-Motorised Transport Measures	Establishment of Footpaths & Facilities	Considers walking as potential mobility option	Ignores the potential of walking as mobility option
	Establishment of Bicycle lanes & Facilities	Considers cycling as potential mobility option	Ignores the potential of cycling as mobility option
	Establishment of Automobile restricted zones	City-centres mostly automobile restricted	Limited application of automobile restrictions
Individual Motorised Transport Measures	Carpooling & other Ride Sharing Programs	Highly organised institutions and services available	Very limited institutions and services unavailable
	Car Rental Services	Easy availability and cheaper option	Limited availability and costlier option
	Fuel and Vehicle Taxes	High cost of vehicle insurances and automobile parts	Moderate cost of vehicle insurances and automobile parts
	Vehicle Improvements (Rain, snow, ice, high temperatures)	Strict enforcement of vehicle improvements	Poor enforcement of vehicle improvements
	Automobile Roadway Repair Service	Services available for towing and recovery	Unavailable services
Multimodal and Intermodal Transport Measures	Road Network Control (Diversion Routes Establishment)	Use of advanced traffic control and traffic information devices	Use of manual traffic control and miscellaneous devices
	Road Section Control (Speed Management, Traffic Control devices)	Use of advanced traffic control and traffic information devices	Use of manual traffic control and miscellaneous devices
	Park & Ride Facilities/Park & Share Facilities	Designated facilities for P&R, P&S	No or limited availability of P&R, P&S
	Alternate Trip Schedules & Trip substitutions	Flexible working hours and teleshopping preferred	Rigid working hours, less impetus on teleshopping
	Inter-operable & Multi-functional Transport	Limited application	Unorganised application
	Multimodal Integrated Time Scheduling/Connection Matching	Use of fixed-timed transfer concept (technical and operational)	Unorganised and manual application
	Trip Chaining/Multipurpose Tours	Facilities provided for one-stop shopping	Undefined concept
	HOV Economic or Preferential Incentives	Limited application observed	No application observed
	Improvement of Traffic Signal Control	Vehicle pre-emption & green-wave principles	No vehicle pre-emption and ineffectiveness of green-wave
	Land use ordinances	Strict enforcement of land use plans	Modifications in land use plans possible
	Traffic & Disaster Information Updates	Use of TMCs, HAR, Navigation systems	No or limited dynamic travel information provided
	Establishment of Work-Zones	Use of advanced traffic control and information systems	Very limited use of traffic control and information systems
Freight Transport Measures	City Logistics System	Organised application in some countries	Unorganised application
	Household Goods Delivery Transportation System	Increasing rate of use of household goods delivery	Very limited use of household goods delivery
	Freight Traffic Operations Control	Fixed loading and unloading zones and times	No fixed loading and unloading zones and time enforcement

3.10 Summary

This chapter provided the definitions, goals and objectives of traffic management. Traffic management is an influence to attain equilibrium between the traffic demand and transport supply. The operative objectives of traffic management are focused on avoiding traffic, shifting traffic and controlling traffic. The mechanisms involved in fulfilling the operative objectives to avoid traffic are focused on linking trips, substituting trips and modifying trips. For the TM objective of shifting traffic, the mechanisms involved are mostly focused on shifting trips in time, mode and destination. Similarly, the TM objective to control traffic deals with mechanisms which influence the transport network, transport modes and the transport users.

Traffic management is considered to influence two areas, traffic demand and transport supply. Traffic demand is influenced by reducing total traffic demand, more efficient utilisation of transport modes, and the selection of effective modes, destination, routes and times of travel. Similarly the transport supply is influenced by transport capacity and supply adaptation and effective traffic management in cases of traffic accident, long and short duration activities, and disturbances that originate from causes other than accidents, incidents and work-related activities.

A total of twelve traffic management modules were established and selected to propose the necessary influences on traffic demand and transport supply in cases of disasters. The classification of traffic management is presented and is based on the category of transport modes (PT, NMT, IMT, MIM and FT) and the requirements of resources for traffic management. The classification of TM measures based on requirements of resources classifies measures into four categories which are: legal and administrative measures, technical and operational measures, economic measures and informational measures.

In order to propose the implementation of traffic management measures, expectations and pre-requisites of TM were studied. These pre-requisites were categorised based on social and organisational pre-requisites, technological pre-requisites, economic pre-requisites and legal pre-requisites. This chapter discussed the potential stakeholders of traffic management and their respective roles and responsibilities. The conflicts and risks created by the application of TM measures were studied. These conflicts and risks were found to be due to persistent to goals and objectives of several TM stakeholders and their estimation methods. The other conflicts were found to be due to counter-effective secondary impacts of TM measures and their compatibility.

Finally, the state of development of traffic management in India and Germany was studied. Several issues related to TM application in India were addressed. The traffic management applications practiced in Germany were also reviewed. The comparisons between India and Germany in the approach and implementation of TM were presented based on five transport modes. As a consequence of the review, the areas of emphases for the applications of TM in Indian conditions are identified.

4 Integration of Traffic Management into Disaster Management

4.1 Introduction

The disaster management require planning efforts prior to the activation of disaster management functions. Planning efforts includes the formulation of policies and proposals; the purpose of which is to anticipate future situations and to provide viable measures accordingly. A successful disaster management plan would ensure that the impacts of disasters are reduced in the long-term by reducing the vulnerabilities that exists in a disaster-prone system. One of many methods is the capacity-enhancement of sub-systems of disaster management including transport. Contemplating the impacts of disasters on transport and the unprecedented role of transport in the disaster management, it is necessary to integrate the sector of transport into disaster management.

In the former disaster management plans, the role of transport was limited to providing adequate supply of transport. The issues related to traffic management (TM) were either ignored or understated. This chapter highlights the integration of traffic management into the four phases of disaster management. The objectives and the sub-objectives of the transport sector are formulated and explained in both the pro-active and the reactive disaster management phases. These formulated objectives of traffic management are then used to develop TM measures and formulate TM strategies in the later chapters. The integration of traffic management also addresses the need of the transport sector to develop transport infrastructure in anticipation of disasters. However, the proposed integration of transport sector including traffic management provided in this chapter does not conflict with the infrastructure development approach of transport sector in disaster-affected or disaster-prone regions. This study is limited to traffic management measures implementable in cases of disasters which influence the existing transport supply and traffic demand generated after a disaster.

4.2 Significance of Traffic Management for Disaster Management

Lack of transport is one of the most evident problems of current disaster management. One of the hypotheses of this study is that traffic management can significantly contribute to the effectiveness of the disaster management functions. Until now (in the disaster management plans) the relevance of transport development and traffic management in most cases is observed only in the post-disaster phases due to pursuing of the post-disaster approach of current disaster management. The literature reveals that the aspects of transport planning and traffic management are often ignored and are not comprehensively stated in current disaster management plans due to inadequate recognition.

The academic publications describes transport development as a critical requirement for disaster management measures but it fails to exhibit the role of traffic management (Carter 1992; Sahni Pradeep 2003; NDMD 2004; IGNOU 2005). Although problems related to transport accessibility and mobility are described as special problem areas of disaster management (Carter 1991; Litman 2006). However, literature review on the current disaster management-approaches failed to reveal the inclusion of traffic management for measures to transport problems. One reason of the exclusion of traffic management is the adoption of a transport development approach for increasing transport capacities for the disaster mitigation. This approach may be partially suitable for disaster situations which experience recurrent problems of extreme transport supply deficit as a result of

disaster impacts. However, in disaster situations where serviceability of transport supply exists, traffic management provides viable solutions compared to cost-extensive transport development. Traffic management also provides equitable demand-side solutions for managing high traffic demand generated during disasters.

Some reasons for the improper integration of traffic management into disaster management are listed as following:

- Disorganisation issues related to unsystematic and inefficient coordination between the traffic management and disaster management stakeholders.
- Lack of understanding on the impacts of disaster on transport supply and traffic demand.
- Insufficient recognition of the role of traffic management for the disaster management functions by the stakeholders of disaster management.

The literature review on disaster management plans also addresses that a management culture of involving the transport sector in the phases of disaster mitigation, disaster preparedness, disaster response and disaster recovery is either absent or in initial stages of development. Moreover, in cases where the transport sector is involved in disaster mitigation and disaster preparedness, the transport measures implementation is mostly limited to the provision of an additional transport fleet (additional vehicles and rolling stock) and a random traffic control measures like traffic restrictions and diversions without much consideration of the impacts.

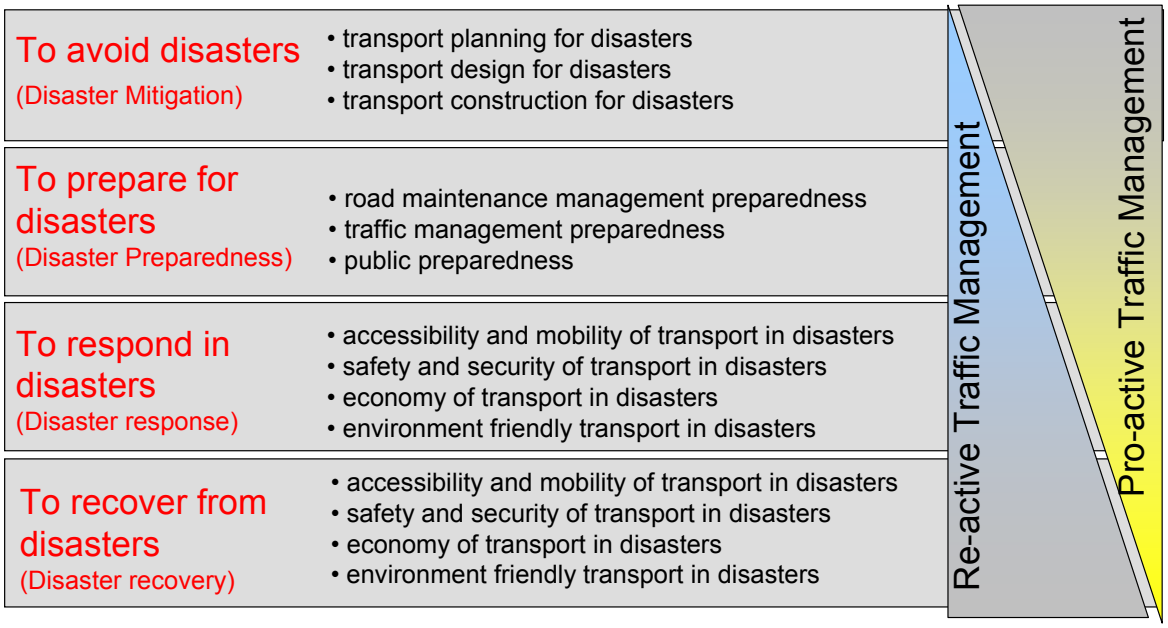


Figure 4-1: Traffic management orientation in disasters

This chapter focuses on providing a framework for the integration of the transport sector into disaster management processes. This framework proposes the necessary transport infrastructure development and traffic management to enhance the process of disaster management.

This framework establishes the aim of transport sector including traffic management for disaster management. The established aim is: **"to support the disaster management functions by providing a disaster-ready traffic and transport system"**. This aim involves four objectives of the transport sector which are:

- **reduce the impacts of disasters on the transport system**,
- **ensure the preparedness of transport system for cases of disasters**,

- **provide transport assistance to disaster response functions of disaster management,** and
- **provide transport assistance to disaster recovery functions of disaster management**.

The sub-objectives of the transport sector are also identified and explained in the framework for each phase of disaster management (Figure 4-2).

In the aftermath of a disaster, an efficient transport sector is important for the success of many disaster management functions. Therefore, it is essential to critically examine the traffic management operations in both the pre-disaster and the post-disaster management phases. By integrating the traffic management into disaster management process, traffic management will be developed and prepared as an effective tool of disaster management.

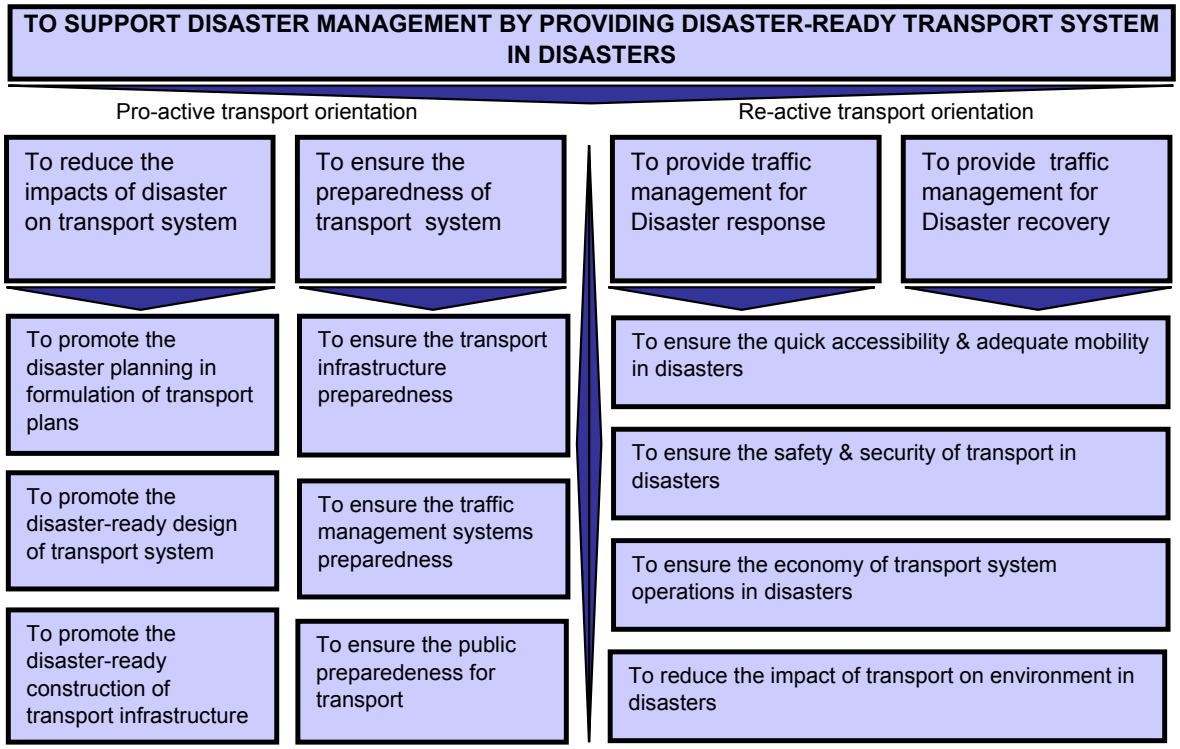


Figure 4-2: Integration of traffic management into disaster management

4.3 Integration of Traffic Management into Disaster Mitigation

Disaster mitigation comprises the actions taken to eliminate or reduce the degree of long-term risk to human life and property from natural and manmade hazards. Disaster mitigation is the involvement of the community, administration, politicians, and decision makers in the reduction of risks through measures at local, regional, and national level. In predictable disasters, disaster mitigation offers a long-term, financially-viable approach of managing natural and manmade disasters. The phase of disaster prevention is prior to disaster mitigation in the complete cycle of disaster management. The disaster prevention process is aimed at preventing the occurrence of a disaster by segregating the vulnerable states (physical, social, economic and environmental factors) from the impacts of hazards (trigger events). In cases where it is impossible to segregate the vulnerable states and hence avoid a disaster occurrence, disaster mitigation and disaster preparedness measures are implemented. The cycle of disaster management is often portrayed in many forms, disaster prevention and mitigation are often considered in one phase in many academic publications (ADRC 2003, 2004). The mitigation measures have a curative impact unlike

preventive measures of disaster prevention. Both prevention or mitigation measures are concentrated in major policy decisions at government level and primarily directed from a higher order of management (Misra, 2004).

The processes required for the disaster mitigation are planned after identifying and assessing the vulnerabilities associated with every hazard in terms of severity and probability. Such vulnerabilities can be related to poor state of transport, housing and power supplies, which are elements at risk in the formation of disasters. The goal of the disaster mitigation in the transport sector is: **"to reduce the impacts of the disaster on the transport system to a minimum"**. Thus, the mitigation of the impacts of a disaster by the transport sector is mainly oriented to improving the **transport infrastructure**, **traffic operations**, and **transport organisation**. Disaster mitigation measures for reducing the vulnerabilities related to transport are mainly focused on the areas of **transport planning**, **transport design**, and **transport construction** of infrastructure in anticipation of disaster impacts. **Transport law**, **transport economics**, and **transport education** are prerequisite areas of transport. The assessment of the hazard impacts on transport and the transport vulnerabilities assessment (in the existing disaster-affected or disaster-prone areas) are necessary for the damage potential assessment of a hazard on transport. This phase recognises the fact that even with a well-established transport infrastructure, traffic operations can be hindered due to ineffective rules of traffic and transport operation, and ineffective traffic organisation of transport users and operators.

Transport development and traffic management are two clearly dissimilar approaches identified to address the transport sector involvement for disaster mitigation. The first approach is known as structural approach in which the transport infrastructure development measures are implemented for disaster mitigation. In this approach, the structural measures for improving roads and transport facilities (strengthening, retrofitting or new construction) are implemented to mitigate the impact of disasters. The second approach is known as non-structural approach in which the traffic management measures are investigated and implemented (without new transport infrastructure development). In this approach, the non-structural measures are implemented which are mostly traffic management measures e.g. political, legal, administrative, economical, operational and information measures to mitigate the impact of disasters.

The sub-objectives of disaster mitigation include the following areas of transport:

- Transport planning**,**
- Transport design**,**
- Transport construction**,**
- Transport law (legal framework, insurance, etc.)**,**
- Transport economics (incentives)**,** and
- Transport education (training and public awareness)

The following sections describe the sub-objectives of the transport sector applicable in the phase of disaster mitigation. Examples for traffic and transport measures implemented during this phase are explained in Table 4-1.

Disaster management in formulation of transport plans

The damages to transport infrastructure due to disaster impacts can be minimised by effective transport planning. The transport planning should consider the geographical, geological and geo-

technical conditions in the development of transport plans in disaster-prone areas. **Risk mapping** and **Environmental impact assessment (EIA)** of each transport development project are useful tools to minimise potential hazard impacts. The alignment of new transport routes should consider all of the potential risks and propose routes with comparatively low or no potential risks. Transport planning is also useful to identify and allocate transport related activities in accordance with the land use plan. The transport development planning should consider the cost of preventive remedial works and other maintenance works which might be necessary in anticipation of a disaster.

Disaster-ready design of transport system

The design of transport facilities in disaster areas should consider the possible impact of disasters on the construction and operation of transport systems. This area deals with the disaster-ready design of transport infrastructure (roads, vehicles and traffic systems). The transport design specifications for various transport systems (roads, bridges, and terminals) should include safety parameters such as seismic loads, snow loads, earth pressures, water pressures, buoyancy effects and temperature changes. The design of transport modes should include the safety specifications for disaster-proof vehicles. The same approach should be followed in the design of traffic control and information systems.

In addition, the infrastructure design must consider special forms of operation needed during disasters e.g. a highway which might be operated in a one-directional mode for the purpose of evacuation must allow the respective guidance of vehicle streams.

Disaster-ready construction of transport infrastructure

The subject of transport planning and design in disasters is aimed at ensuring disaster-proof transport construction. It is therefore important to implement planning and design principles for the construction of transport infrastructure in disaster-prone areas. The transport construction should not deviate from any disaster design standards or specifications. Even after construction, regular monitoring and inspections are required to identify any unusual conditions (such as pavement failures and cracks) which are larger risk during a disaster. A **Road Safety Audit (RSA)** and **Road Safety Inspection (RSI)** are standardised procedures to check the safety of any transport infrastructure construction and the maintenance. The RSA and RSI should include the check for the state of transport infrastructure in cases of disasters. It is an inventory or checklist of the features in transport infrastructure which might affect the safety of the transport system. Road safety audits instigate the corrective measures to improve the safety of the transport construction or facilities. The results of RSA are then used for evaluation procedures to estimate the damage potential (damage potential assessment) of transport construction and facilities for different disaster types.

The following sections describe the supporting areas of transport necessary for disaster mitigation and disaster preparedness.

Transport law

The subject of transport law includes all special laws, regulations and ordinances required for reducing the disaster impacts on the transport system. It focuses on the establishment of a legal framework, establishment of rules and their enforcement. In cases where the transport laws are inadequate for ensuring the correct implementation and effectiveness of reactive measures, this subject will provide the establishment of safety codes for transport construction in disaster-prone areas, special traffic regulations and trip reduction ordinances among others.

Transport economics

Transport economics is an important subject for the reduction of economic vulnerabilities related to transport by providing economic incentives to the transport users and operators. Transport policies concerning the economic incentives should be formulated prior to disaster response and recovery. The economic incentives provided during response and recovery period will minimise disaster impacts on transport system. The transport operators are provided economic incentives in the form of subsidies and tax exemptions for transport infrastructure development and transport operations in disaster-prone areas. Economic incentives are also provided to upgrade the current vulnerable transport system to disaster-proof transport system.

Transport measures category	Examples of traffic and transport measures during disaster mitigation phase
Administrative and organisational measures	Development and implementation of disaster planning ordinances
	Development and implementation of land use zoning ordinances
	Obligatory environmental impact assessment of transport development projects
	Inspection of transport facilities like roads, bridges, culverts, tunnels etc.(Safety audit)
	Inspection of public and private transport modes (Safety audit)
	Developement of disaster command control system
	Inter-State transport service agreements
	….
Economic measures	Tax Exemption for inter-state transport services
	Development of subsidy policies for PT operators
	Development of subsidy policies for immobile user groups
	Development of insurance policies for transport operations
	Provision of soft loans for disaster-resistant transport upgradation
	….
Technical/ operational measures	Developement and implementation of design standards for transport construction in disaster areas
	Developement and implementation of design standards for disaster transport modes
	….
Informational measures	Public awareness programs
	Providing Public education
	Conducting Staff training
	Disaster response drills and exercises
	Development of new transport information techniques
	…

Table 4-1: Examples of traffic and transport measures in disaster mitigation phase

Transport education

The impacts of disasters on the transport system can be mitigated by providing adequate transport education, conducting staff training, response drills and exercises. The transport users and operators should be made aware of the nature of hazards and the present vulnerabilities, and the knowledge of the implementable transport development and traffic management measures in disasters. Awareness campaigns are required in the vulnerable communities to inform the public on transport procedures in different disasters. The transport users should be issued guidance on evacuation procedures, intended road user behaviour and different traffic advisories for different types of disaster.

Transport education also is the key to solve several problems related to high incidence of traffic violations, poor rationality (maladaptive behaviour) and poor selection of speed, route, destination and time. Transport education on command and control (organisational structure) is necessary to mitigate transport problems due to improper coordination of disaster management and traffic management stakeholders. The examples of traffic and transport measures implemented during disaster mitigation are explained in Table 4-1.

4.4 Integration of Traffic Management into Disaster Preparedness

The objective of disaster preparedness is to attain a certain level of readiness to respond to a specific or a common disaster through measures that strengthen the technical and management capacities of governments, organisations, and communities (IGNOU, 2005).

Similar to disaster mitigation, the preparedness phase is pro-active in nature and aims at reducing or preparing to overcome disaster impacts on the society. The response and recovery from disaster impacts demand logistics and transport preparedness, which includes transport infrastructure preparedness, traffic management systems preparedness and public preparedness. The transport sector preparedness is essential because the disaster impacts are unknown and cannot be minimised through infrastructure development only. Short-term preparedness is needed in cases of predictable disasters; however preparedness is also needed for unpredictable disasters in a long term.

The earlier described disaster mitigation measures of transport sector also provide a framework for transport preparedness in disasters. In cases where the disaster mitigation measures are not available or implemented, disaster preparedness measures can encounter several problems of implementation due to lack of procedure, lack of training and lack of organisation. Traffic and transport preparedness pre-requisites measures in the areas of transport infrastructure, transport law (legal) and transport education (organisation). In order to develop quick intervention capacity through transport preparedness during disasters, traffic management develops plans to share the use of available transport resources and optimise them by administrative, organisational, economic and information measures. Transport preparedness also develops transport operations capacities to facilitate an effective transport response in disasters.

The sub-objectives of disaster preparedness include the following aspects of transport:

- Transport infrastructure preparedness
- Traffic management systems preparedness
- Public preparedness

As explained in the section of disaster mitigation, transport preparedness for cases of disaster also follows two different approaches, structural approach (transport infrastructure preparedness) and a non-structural approach (traffic management systems and public preparedness).

Transport infrastructure preparedness

Most of the natural disasters affect the transport system through bad weather conditions such as black ice, heavy snow, extreme road temperatures, heavy rainfall and storms among other weather conditions. In disaster mitigation phase, a damage potential assessment of the important transport infrastructure is conducted. Based on the damage potential assessment through RSA and RSI in bad weather conditions, regular monitoring of vulnerable transport systems is conducted. In cases, where damage potential is high, the transport infrastructure preparedness includes temporary

construction and repair for strengthening or retrofitting of transport facilities for e.g. ice control, snow fencing and fog dispersal among other measures. Transport infrastructure preparedness measures are either preventive or protective in nature based on the individual disaster type characteristics.

Traffic management systems preparedness

Traffic management involves preparedness of transport supply for the anticipated traffic demand. Preparedness in this section consists of procurement, storage, and operation of traffic control devices (traffic signs, road markings, traffic signals, and alternate power and communication equipments) and information systems (road and weather monitoring stations, passenger information systems). This type of preparedness is referred to as transport supply preparedness. The preparedness is also required in terms of adequate establishment of laws which may include evacuation plan, signal timing plan, detours plan or access restriction plan (traffic operation preparedness), regulations and ordinances (legal preparedness). Finally, the preparedness is required in terms of planning the traffic operations based on formulated strategies.

Intended impact of TM measure	Mechanisms	Examples of TM measures	Examples of TM preparedeness
To avoid traffic	• linking trips • substituting trips • modifying trips	Trip chaining & multipurpose tours	Development of program
		Trip reduction ordinances, special traffic regulations	Establishment of laws and regulations
		Household deliveries	Establishment of home delivery system
To shift traffic	• alternate times • alternate modes • alternate destinations	City logistics system	Establishment of city logistics system
		Inter-operable transport	Interoperability of transport preparedness
		Diversion routes, evacuation routes	Development of diversion and evacuation plans
To control traffic	• network • transport modes • transport user	Signalised traffic control	Development of signal timing plan
		Vehicle improvement (tyre chains, reflector devices etc.)	Set up automobile repair centres
		Disaster and traffic related information	Establish disaster and traffic information service

Table 4-2: Possible mechanisms of traffic management preparedness

Public preparedness for transport

Transport maintenance and traffic management staff, transport users, and non-transport users require being prepared in anticipation of a disaster. Transport education, training and exercises are necessary tools for public preparedness. The focus of education, training, and exercises is to acquaint the public with the importance, understanding and knowledge of new traffic laws, regulations and ordinances that are likely to be imposed during disasters. Public participation is a pre-requisite for public acceptance for the intended road user behaviour and this aspect should be adequately addressed in the subject of public preparedness.

The essential consideration of transport preparedness plans should be comprehensiveness in assessment of transport requirements. Preparedness plans demand clarity of aim, realism, level of planning, flexibility, coordination, assignment of responsibilities, ease of use, and viability.

The examples of traffic and transport measures implemented during the phase of disaster preparedness are explained in Table 4-3.

Transport measures category	Examples of traffic and transport measures during disaster preparedness phase
Administrative and organisational measures	Establishment of disaster organisational system
	Establishment of traffic management centre
	Development of formal and informal car-sharing programs
	Modification of closing times of offices
	Establishment of formal agreements for transport control
	Inventory of disaster transport reserves
	….
Economic measures	Economic incentives for transport operations like towing, repair and hauling
	Full tax exemption for transport
	Economic incentives or disincentives for a transport modes
	Economic incentives or disincentives for a transport route
	….
Technical/ operational measures	Patrolling, inspection & monitoring of road conditions
	Development of traffic restriction plan
	Development of traffic detour plan
	Development of evacuation plan
	Development of contingency plan
	Speed-limits plan for accident prone zones
	Green-wave coordination plan
	Allotment of parking spaces
	Establishment of ready to use monitoring and warning system
	Establishment of ready to use emergency lanes on highways
	Back up supply of power and communications
	….
Informational measures	Provision of weather related information
	Provision of congestion information
	Provision of incident information
	Provision of warning system
	Provision of other related information
	….

Table 4-3: Examples of traffic and transport measures in disaster preparedness phase

Preparedness measures are generally oriented towards measures by individual organisations as compared to disaster mitigation measures, which are usually oriented towards major policy decisions at government levels. Traffic management preparedness consists of preparation of installing or monitoring of warning systems; traffic communications set-up; traffic evacuation plans; resource inventories; traffic personnel/contact list; mutual aid agreements; and public information and education. The traffic management measures in this phase are oriented towards ensuring the logistical readiness to deal with any particular disasters, which can be activated in disaster response and recovery phases.

4.5 Integration of Traffic Management into Disaster Response

The disaster response and disaster recovery phases are reactive in nature and aim at responding and recovering from the impacts of the disasters. The disaster response measures are actions taken shortly before, during, or directly after the disaster occurrence to save lives, minimise damages to the property, and to enhance the effectiveness and speed of recovery.

The integration of traffic management into the disaster response is necessary to support the urgent requirements of DMF's e.g. disaster control (fire control, flood control, search and rescue, disasters

involving evacuations, etc.) and medical care among other functions of disaster management (see Figure 4-3).

Traffic management in the disaster response phase aims at ensuring transport accessibility and mobility, transport safety and security, transport economy and transport environment. The requirements of traffic management for the individual disaster management functions are mostly unknown. Therefore there is a need to evaluate the transport supply and traffic demand requirements which are fulfil the needs of disaster management functions. In order to integrate the traffic management into disaster response, the understanding of the aim, objectives and processes involved in the disaster response is essential. Furthermore, the knowledge about the disaster type characteristics related to damage potential on transport infrastructure, transport modes and transport operations is required. Traffic management needs to be coordinated with the activated disaster management functions (agencies responsible for food supplies, medical care, housing, etc.) for activating the appropriate TM measures (see Table 4-4).

The typical sequence of disaster management functions during the response and recovery phases and the respective transport requirements are shown in Figure 4-3. The traffic management measures in these phases are mostly reactive and include mainly technical and informational measures. In order to implement these types of measures, the administrative, organisational, legal and economic measures should be implemented in preparedness for disasters in the phases of disaster mitigation and disaster preparedness.

The following sections describe the sub-objectives of the transport sector especially traffic management in the disaster response phase.

Quick accessibility & adequate mobility in disaster response

The transport accessibility and mobility is hindered during disasters and special traffic management measures should be implemented to gain the desired levels of transport accessibility and mobility. Traffic management in this phase is intended to fulfil mobility requirements of the disaster-affected or disaster-prone people. The mobility includes both, the trips by ordinary people and the trips generated by the disaster management functions. Transport accessibility is a pre-requisite to fulfil mobility. Accordingly, this phase also intends to provide adequate accessibility of destinations, modes and services. Traffic demand in cases of disasters varies according to geographical scale, duration of impact, and type of impact on the people among other variables. The traffic demand during disaster response (for e.g. disaster control, medical care, etc.) demands its urgent fulfilment and emphasis upon importance of trip speed, trip safety and trip time. However the traffic demand which increases gradually with time emphasises mostly upon trip frequency and trip time.

Safety & security of transport in disaster response

Traffic incidents such as vehicle breakdowns and road accidents are very common during disasters. These incidents can decelerate the disaster response and pose a threat to many disaster management functions. Some publications use term for such incident occurrences as secondary disasters. These traffic incidents demand additional traffic operations and pose a serious risk to scarcely available transport resources in disasters. Therefore, the measures of this phase are focused to provide safety and security to all transport modes (PT, IMT, IMT, FT, etc.). The traffic management implements several TM measures to shift traffic to other safer modes or effective traffic control measures.

This issue of transport safety is unaddressed or understated in many disaster management functions including logistics and transport. Critical infrastructure protection is another area of security of transport system. It consists of preventive and protective measures to protect essential transport infrastructure required during disasters.

In cases of unpredictable disasters, the traffic management and transport development uses many available modules for implementation such as road weather management, road maintenance management and traffic incident management. Due to the dynamic nature of traffic incident management the same principles can be applied for the measures of dynamic traffic management in disasters.

The following sections give the processes involved in the traffic incident management. Traditionally traffic incident management (TIM) consisted of following steps: (i) **detection**, (ii) **verification**, (iii) **response**, (iv) **site management**, (v) **clearance**, and (vi) **recovery**. Traffic management is applicable in all the above steps. These individual steps of traffic incident management applicable in cases of disasters are explained in the following:

Detection

The disaster detection is the determination by the responding authority that the disaster has occurred and includes the detection of traffic conditions, too. The detection of the disaster could be done by public, road surveillance systems, advanced weather information systems, media or some other sources. Literature depicts that most major disasters are detected within minutes by road surveillance systems e.g. traffic monitoring stations using CCTV and PTZ cameras.

Verification

Disaster verification is the determination of the precise location, impact and other characteristics of the disaster. In case the detection is done by the outside sources, this information is delivered to the concerned authorities such as police, ambulances, and fire control authorities among others. Accurate and detailed information about the disaster enable the traffic management to make decision on the type, scale and duration of traffic management (see Table 4-4).

Response and site management

Disaster response is the activation of a planned strategy for the safe and rapid deployment of the most appropriate personnel and resources to the disaster site. It is observed that the traffic management is the least developed element in most disaster response functions especially site management. It is also observed that the corridor and the system level traffic management is often not realised in practice for the requirements and benefits of DMF. The implementation of traffic management for disaster response (DMF functions) can considerably reduce the traffic problems during disasters and considerably reduce the time of disaster response and recovery.

Some publications consider the disaster site management as a part of disaster response. Disaster site management is the management of resources to prepare for clearance and recovery of disasters and includes traffic management to divert traffic flow entering or leaving the disaster site. The disaster site management might involve the development of temporary or permanent work zones for site management which might operate under the popular incident command system (approach followed nationwide in the United States).

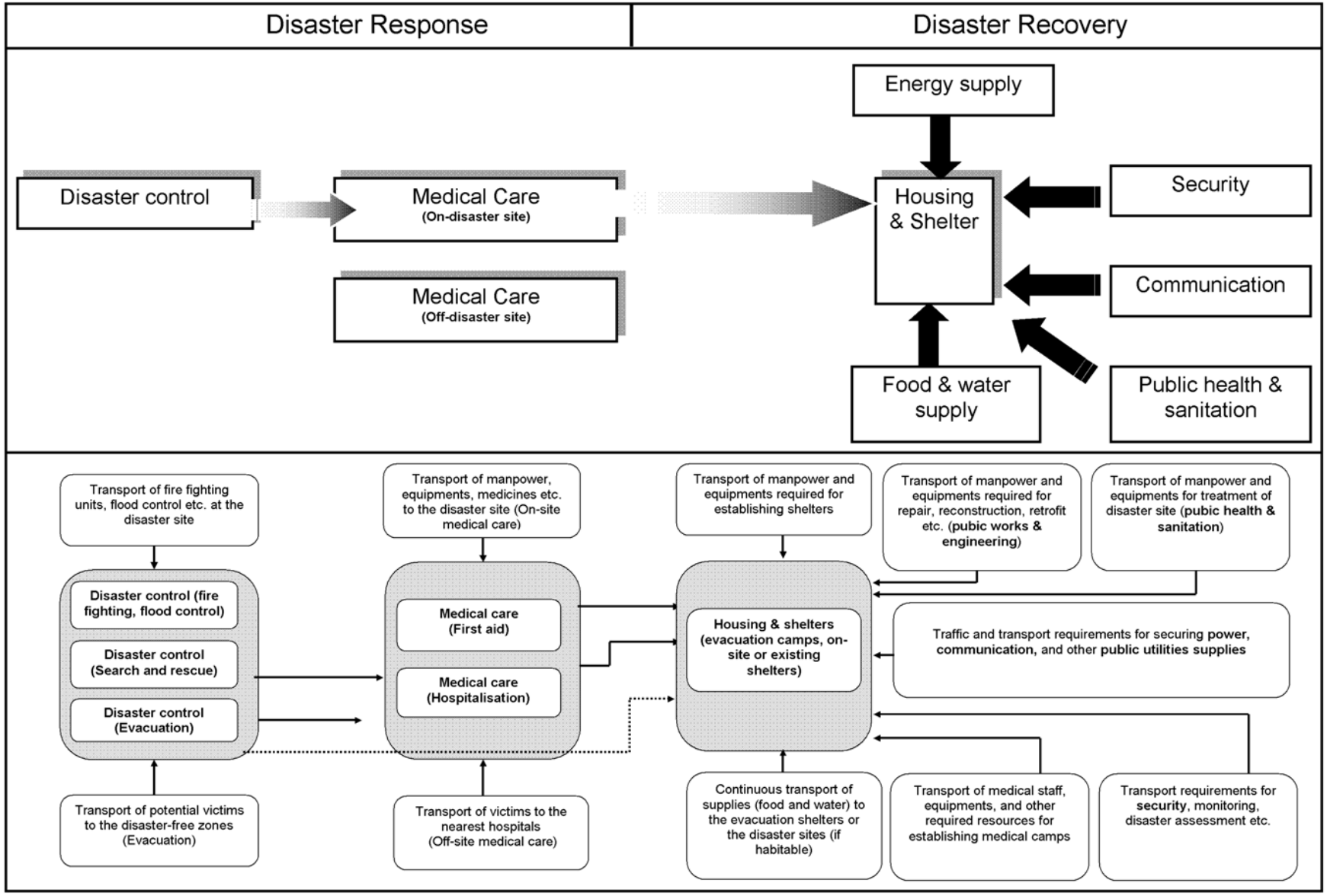


Figure 4-3: Sequence of disaster management functions and their transport requirements

Economy of transport system operations in disaster response

The poor economic state of the people, State and the Nation is critical to the disaster response. In this sub-objective, the issues related to poor economics of society are addressed and possible measures to minimise the transport costs borne by the transport users and operators are investigated. Transport economics deals with the provision of economic incentives to transport users and operators. The economic incentives are provided in the form of subsidy and tax-exemption for traffic and transport operations during disasters. The purpose of providing economic incentives for transport users and operators is to reduce the vulnerabilities of transport. Thus, transport economics is an important area for the reduction of physical, social, economic and environmental vulnerabilities.

Reduce the impact of transport on environment in disaster response

The issues of transport environment are considered less significant in the disaster response phase by disaster managers. This fact of less importance of transport environment is due to trade-off of other sub-objectives of transport such as transport accessibility and mobility, transport safety and security, and transport economy with transport environment. Disaster response consists of measures implemented in life-threatening situations where fulfilling the economic and environmental objectives is considered to have less priority. However, the disaster response in non-life threatening situations should propose traffic management measures which aim at reducing the environmental degradation by adopting non-motorised transport and public transport measures.

Furthermore, disaster management should not violate the traffic laws (local, State and national traffic laws) applicable in disaster-affected area and ensure that traffic management is sustainable by providing environmentally sustainable measures. Traffic management should not degrade the environmental quality by promoting destinations, routes, modes which are not sustainable.

Disaster related information	Units	Purpose of information	Examples of traffic management decision support
Geograhical scale	km^2	Anticipated type of traffic management	Urban traffic control/Inter-urban traffic control, Amount of traffic, etc.
Warning time	hours	Traffic mangement preparedness time	Time available to implement the disaster specific traffic management strategies
Response timeline	days/months	Traffic management activation time	Time until the traffic management is activated
Recovery timeline	days/months/years	Traffic management activation time	Time until the traffic management is activated
Casualties/Injuries	No. of deaths/Injuries	Type of traffic generated	Amount of emergency traffic (medical care)
Infrastructure damage	Total area damaged	Type of traffic generated	Amount of construction and repair traffic (Work zones bound)
Evacuation/Quarantine operation potential	No. of people affected/displaced	Type of traffic generated	Amount of evacuation traffic
Contamination/other health hazards	No. of people or sites affected	Type of traffic generated	Amount of freight traffic
Disaster management functions activated	No. of trips/disaster support function/day	Type of traffic generated	Amount of traffic from other DMF activities
Potential of secondary disaster (accidents/incidents)	Accidents/day	Anticipated type of traffic management	Accident and Incident traffic management activation
O/D of DMF activities	Area of activity	Anticipated type of traffic management	Urban traffic control/Inter-urban traffic control

Table 4-4: Examples of decision support for traffic management in disasters

Transport measures category	Examples of traffic and transport measures during disaster response phase
Administrative and organisational measures	Compulsory closing of public and private establishments
	Procurement of company vehicles
	Inter-operable transport ordinances
	Trip-chaining programs
	Land-use modification
	Alternative or flexible work schedules
	….
Economical measures	Provision of economic or preferential incentives and disincentives for alternate mode use
	Provision of economic or preferential incentives and disincentives for alternate times of transport
	Provision of subsidy on automobile parts for vehicle improvement
	Certificate scheme for disaster tourists and research groups
	….
Technical and operational measures	Public transport network, scheduling and accessibility improvement
	Operation of car pooling and car rental services
	Operation of diversion routes
	Lane management and control
	Speed zoning and management
	Traffic signal control and coordination
	Lighted traffic bollards
	Visibility enhancement devices
	Establishment of freight parking zones
	….
Informational measures	Information dissemination (commercial radio and television)
	Information dissemination (information kiosks)
	Information dissemination (local newspapers)
	Information dissemination (dynamic message signs)
	Information collection (Wireless communication)
	Information collection (Traffic monitoring stations)
	….

Table 4-5: Examples of traffic and transport measures in disaster response phase

4.6 Integration of Traffic Management into Disaster Recovery

Disaster recovery phase consists of long-term activities to return vital life support systems to minimum operating standards or even improved levels (Sahni, 2003). Disaster management functions in this phase are related to repair and construction (public works and engineering), rehabilitation (public health), and development of temporary and permanent shelters (housing) among other disaster management functions.

Clearance and recovery

The clearance and recovery activities in disaster recovery phase are the long-term activities of disaster management. The main focus of the traffic management in this phase is to remove the roadway obstructions and restore the traffic flow to its full capacity. This might include towing, clearance of roads of any stalled vehicle, wreckage, debris, or spilled material on roads as a result of disaster impacts.

Traffic management in disaster recovery phase is aimed at resuming the traffic operations to normal or improved levels and to assist the disaster management functions of their need of traffic

management. Although the sub-objectives of transport sector in disaster recovery phase are similar to those in disaster response phase, the TM measures implemented in the disaster recovery are different than the disaster response.

Traffic management involves a large potential to reduce the time required (detection time, response time, clearance time and recovery time) for the disaster response and disaster recovery. Some benefits of saving time include:

- increased survival rate of the disaster victims,
- reduced delay of disaster management functions,
- improved response time to speedy response and recovery,
- improved air quality and,
- reduced occurrence of accidents (referred in disaster management as secondary disasters).

In the following sections the sub-objectives of transport sector in disaster recovery are explained with examples.

Quick accessibility & adequate mobility in disaster recovery

Traffic management is required to restore the traffic flow at a disaster-affected site (Disaster Site-management). Traffic management in this phase is mainly aimed at managing traffic flow, establishing priorities, coordinating with disaster management organisations and maintaining communications. An adequate accessibility to the disaster-affected areas is required with suitable mobility options for all modes of transport.

In disaster situations where evacuations are made, traffic management is activated for the re-entering of evacuees back to previously evacuated area after normalcy is attained (Re-entry management). The traffic management measures in this phase include alternate route planning (diversion route), traffic control, queue management, etc.

Safety & security of transport in disaster recovery

The post-disaster recovery includes numerous repair and construction activities in the disaster-affected areas (Work-zones). This generates construction traffic of heavy commercial vehicles (HCV). Conflicts are created between construction and normal traffic (involving IMT, NMT, PT, etc.). Thus, traffic management is required to ensure the safety of transport users within and outside the limits of work-zones. Work-zone management needs to apply traffic management during the establishment of stationary and mobile work zones. It includes TM measures to provide work-zone traffic control, route planning and time scheduling for construction and normal traffic.

The mechanisms of traffic incident management could be applied for traffic-related incidents at or near work-zones in the disaster recovery phases.

Economy of transport system operations in disaster recovery

Economics of transport is severely affected due to the following factors: (i) improper utilisation of available transport capacities, (ii) ineffective traffic operations, and (iii) improper organisation of transport users and operators. This results in the high operating costs (fixed and variable operating costs) of transport services (freight and passenger services) during disasters.

Traffic management in disaster recovery needs to support the logistics of disaster management functions. TM can assist in the timely supply of construction materials, equipments and manpower at desired locations. This TM support will involve the implementation of TM measures which

reduce freight trip time and provide prioritised entry to different vehicles. The benefits incurred from such TM support are economic benefits due to reduction of long-term disaster recovery phase.

Traffic management bears a potential to reduce the operating costs of all transport modes (PT, IMT, MIM and FT).

Reduce the impact of transport on environment in disaster recovery

Generally, the large scale traffic and transport operations in disaster recovery generate high air and noise emissions. There is a need to maintain or improve environmental quality of transport to promote sustainable habitats. Literature reveals that the environmental issues of transport are inadequately addressed in the current traffic management. However, traffic management has a strong potential to reduce the air and noise emissions through the implementation of TM measures e.g. freight operations control, city logistics system, etc.

Transport measures category	Examples of traffic and transport measures during disaster recovery phase
Administrative and organisational measures	Inter-operable transport ordinances
	Land-use modification
	Public transport management centre
	Disaster traffic priority system
	City logistics system
	Work- zone coordination & management
	….
Economical measures	Provision of economic or preferential incentives and disincentives for alternate mode use
	Provision of economic or preferential incentives and disincentives for alternate times of transport
	Provision of subsidy on automobile parts for vehicle improvement
	Certificate scheme for disaster tourists and research groups
	….
Technical and operational measures	Public transport capacity improvement
	Establishment of pedestrian routes & facilities
	Establishment of bicycle routes & facilities
	Automobile roadway repair service
	Diversion routes and special routes establishment
	Access and parking restrictions
	Development of temporary and permanent work zones
	Establishment of freight parking zones
	….
Informational measures	Information dissemination (commercial radio and television)
	Information dissemination (information kiosks)
	Information dissemination (local newspapers)
	Information dissemination (dynamic message signs)
	Information collection (Wireless communication)
	Information collection (Traffic monitoring stations)
	….

Table 4-6: Examples of traffic and transport measures in disaster recovery phase

The formulation of sub-objectives of the transport sector (including traffic management) in disaster response and disaster recovery phases is similar but there are differences in the application, approach and duration of TM in disaster response and recovery phases. Some of these differences are explained in the following:

- TM measures in disaster response are generally short-term and dynamic TM measures compared to long-term and static TM measures for disaster recovery. One of many traffic demand characteristics during the recovery phase is the large number of trips and the rate of increase of trips is gradual. Conversely, in disaster response phase, the traffic demand is comparatively less and necessity to fulfil the traffic demand is immediate.
- TM measures implemented in disaster response phase have a direct implication on improving the safety of people. On the contrary, TM measures in disaster recovery are generally implemented in non-urgent conditions and hence lack TM motivation, acceptance and coordination of many stakeholders of disaster management including traffic management.
- TM measures in disaster response phase are implemented under special organisational and political framework with major exceptions of jurisdictions and limits of authorities. On the contrary, recovery measures are mostly confined to dedicated organisational and political framework without the major exceptions of jurisdictions and limits of authorities. Traffic management in disaster response enforces special rules, regulations and ordinances which are difficult to implement during disaster recovery. Traffic management measures during disaster response are sometimes implemented without consideration of long-term implications on disaster recovery.
- TM measures in disaster response attain higher level of public acceptance. This public behaviour is due to the more convincing nature of TM measures in disaster response. Conversely, the enforcement of similar measures in disaster recovery is difficult due to lesser coordination and low public acceptance of those measures.

The processes involved in the transition of disaster response to disaster recovery in actual disaster conditions are not appropriately demarcated. Consequently, the TM measures are indifferent in both phases, which adversely affect the DM. Thus, it is necessary to understand the characteristics of disaster response and disaster recovery in the context of traffic management. Accordingly, the TM measures should be well segregated based on specific disaster response and disaster recovery requirements. Due to the long phase of disaster recovery, TM should propose measures that are economically viable to the disaster-affected regional economy and largely acceptable by the public. Such measures should aim at enhancing productivity of the transport system.

Table 4-7: Traffic management measures in disaster management phases

	Measures	Type	Category	Mitigation	Preparedness	Response	Recovery
1	Economic or preferential incentives and disincentives	ECO	Multimodal and Intermodal Transport	◪	○	○	●
2	Trip reduction ordinances	ADMN	Multimodal and Intermodal Transport	◪	○	●	●
3	Special transport service (agreements)	ADMN	Multimodal and Intermodal Transport	◪	○	●	○
4	Special traffic regulations	ADMN	Multimodal and Intermodal Transport	◪	○	●	○
5	Land-use modification	ADMN	Multimodal and Intermodal Transport	◪	○	●	●
6	Carpooling schemes	ADMN/INFO	Individual Motorised Transport	◪	○	●	○
7	Multimodal integrated time scheduling	TEC	Multimodal and Intermodal Transport	○	◪	●	○
8	Development of city logistics system	TEC	Freight Transport	○	◪	○	●
9	Inter-operable transport	TEC	Multimodal and Intermodal Transport	○	◪	●	○
10	Capacity increment of public transport vehicles	TEC	Public Transport	○	◪	●	○
11	Road Pricing	ADMN	Individual Motorised Transport	◪	○	○	●
12	Trip chaining program	ADMN/TEC	Multimodal and Intermodal Transport	○	◪	○	●
13	Vehicle improvement program	ADMN/TEC	Multimodal and Intermodal Transport	○	◪	●	○
14	Disaster traffic priority system	ADMN	Multimodal and Intermodal Transport	○	◪	●	○
15	Disaster training and exercises	ADMN	Multimodal and Intermodal Transport	○	◪	●	●
16	Disaster traffic control centre	ADMN	Multimodal and Intermodal Transport	○	◪	●	●
17	Disaster and traffic information service	INFO	Multimodal and Intermodal Transport	○	◪	●	○
18	Access restriction and control	TEC	Individual Motorised Transport	○	◪	●	○
19	Lane management and control	TEC	Individual Motorised Transport	○	◪	●	○
20	Establishment of diversion routes	TEC	Individual Motorised Transport	○	◪	●	○
21	Ramp metering and control	TEC	Individual Motorised Transport	○	◪	●	○
22	Speed zoning and management	TEC	Individual Motorised Transport	○	◪	●	●
23	Improvement of signalised traffic control	TEC	Multimodal and Intermodal Transport	○	◪	●	○
24	Improvement of non-signalised traffic control	TEC	Multimodal and Intermodal Transport	○	◪	●	○
25	Parking management	TEC	Individual Motorised Transport	○	◪	●	●
26	Establishment of pedestrian routes & facilities	TEC	Non-Motorised Transport	○	◪	●	○
27	Establishment of bicycle routes & facilities	TEC	Non-Motorised Transport	○	◪	●	○
28	Public transport routing improvement	TEC	Public Transport	○	◪	●	○
29	Public transport scheduling improvement	TEC	Public Transport	○	◪	●	○
30	Public transport accessibility improvement	TEC	Public Transport	○	◪	●	○
31	Capacity increment of public transport vehicles	TEC	Public Transport	○	◪	●	○
32	Improvement of intermodal facilities	TEC	Multimodal and Intermodal Transport	○	◪	●	○
33	Household goods delivery transportation system	ADMN/TEC	Freight Transport	○	◪	●	○
34	Traffic incident management system	ADMN/TEC	Multimodal and Intermodal Transport	○	◪	●	○
35	Work zone management system	TEC	Multimodal and Intermodal Transport	○	◪	●	○

Legend:

● Reactive disaster management phase

◪ Pro-active disaster management phase

4.7 Summary

Literature revealed that the role of traffic management is not adequately addressed in the disaster management plans. This fact provided the motivation to present the integration-framework of traffic management into disaster management in the four different disaster management phases. The availability of integration-framework will assist in the inclusion of traffic management in the mainstream of disaster management. The presented integration-framework is based on the objectives and sub-objectives of traffic management in disaster management phases. In the mitigation phase of disaster management, TM needs to formulate plans, design the disaster-ready transport systems and promote the disaster-ready construction of the transport facilities. Similarly, in the preparedness phase of disaster management, traffic management needs to consider traffic infrastructure preparedness, traffic management systems (information and control systems) preparedness and public preparedness (transport user and non-transport user). In both post-disaster phases i.e. disaster response and disaster recovery phases, the traffic management deals with providing access, mobility and safety. Traffic management also ensures the economy and environment related to transport. The differences in the approach of traffic management in disaster recovery persist due to activation of different disaster management functions than in disaster response phase.

5 Traffic and Transport Problems in Cases of Disasters

5.1 Introduction

Natural disasters (cyclones, floods, tornadoes) and manmade disasters are threats to the effective functioning of transport system. Logistics and transport is an essential disaster management function (DMF) for the pre-disaster and post-disaster management processes. A transport system is one of the most vulnerable elements to the impacts of a disaster. Large scale disasters tend to generate a high traffic demand due to urgent needs of mobilisation of resources at national, regional and local levels to aid the disaster response and recovery. Transport sector is not limited to restore the mobility levels but also to provide the traffic and transport operations assistance to other disaster management functions for effective disaster response and disaster recovery. In order to fulfill the aim and objectives of the transport sector in disasters, a traffic management is employed which effectively allocates the use of transport supplies with respect to the traffic demand. However, traffic management both as an organization and as a process faces problems due to the disaster impacts and the prevailing boundary conditions of the disaster-affected or prone area.

An integral part of any effective planning process is the determination of problems that limit the ability to meet the stated goals and objectives. This chapter describes the prevalent problems encountered by traffic management in disasters. These problems are differentiated based on the disaster impacts on:

- **transport infrastructure**,
- **transport vehicles**, and
- **transport users including transport operators**.

The transport issues and concerns due to prevailing boundary conditions of the disaster-affected area are also explained. The prevailing boundary conditions affect the transport development of the region and subsequently the traffic management in the disaster-affected areas. The identification of traffic and transport problems during disasters is a tool to provide the traffic management operational framework given in next chapter. The goals and objectives of traffic management explained in the framework are derived from the traffic and transport problems study conducted in this chapter.

The traffic management problems and issues are derived from extensive literature review, characteristics of the study area (Nagapattinam, State of Tamil Nadu, India) and several disaster impact assumptions. These problems given are not comprehensive for all disasters but they represent the typical problems in majority of disasters.

5.2 Basic Disasters Impacts

In this section the basic impacts of disasters are described which may cause traffic and transport problems regarding the transport infrastructure, transport modes (vehicles), and the transport users including the transport operators. The transport situation during disasters is the combination of several attributes such as disaster impacts on traffic demand and transport supply, transport development state, and transport operation performance. The relationship between the given attributes is quite complex, and it is difficult to credit a transport situation through an individual attribute. This study defines hypothetical transport situations in disasters which are the basis of traffic management goals and for the objectives of the TM operational framework and the

formulation of TM strategies. In order to define the transport situation, the following basic impacts are considered:

- The transport infrastructure (primary and ancillary road infrastructure) may sustain damages which may result in reduced capacity and hence reduced accessibility for disaster response functions such as disaster control and medical care. Disasters may affect people within and outside the impacted area by reducing their mobility. The accessibility and mobility may improve with the necessary repair of transport infrastructure (roads, control devices, etc.) and the traffic management measures (diversion routes, access restrictions, etc.).
- The traffic demand may increase in the disaster impacted area requiring additional transport assistance from the neighbouring states and central government.
- The impact of a disaster or hazard may create an evacuation traffic demand (both spontaneous and pre-planned evacuations) at high-risk areas. The evacuation situation may vary depending on warning time, evacuation preparation and public warning.
- Damages to power supply and disruption of communications may be caused. These damages may inhibit traffic management and result in inoperability of some transport infrastructure and transport modes. Traffic management uses power and communications, its unavailability will cause poor traffic control and inefficient coordination between various stakeholders of transport sector and disaster management. The unavailability of power and communication will demand alternate transport infrastructure and control (backup supplies).
- The ancillary infrastructure such as terminals, bus stations, fuel stations and other street furniture may sustain damages. The maintenance and construction resources may be deficient. Thus, such infrastructure resources will probably exceed local availabilities.
- The traffic flow during the disaster response and recovery phases may create congestion in the transport network both at local and regional level which will demand new measures of traffic management. However, this study is limited to proposing traffic management measures in urban and inter-urban areas.
- The vehicles may sustain damages due to disasters which may limit vehicle operation. The inoperability of transport modes may create demand for alternate and additional transport modes. In general the performance of existing modes (vehicle performance) may be reduced which could probably cause hindrances to traffic flow. The vehicle performance will improve with the vehicle improvement, infrastructure repair, and infrastructure strengthening efforts.
- The affected victims of disasters may suffer from “disaster syndrome’’ which could affect their rationality and behaviour. For example some people might refuse to evacuate the disaster-impacted area regardless of the circumstances. The people may display irrational behaviour involving poor travel decisions and traffic violations. Institutional participation and public acceptance may be severely affected due to unacceptable transport user and operator behaviour. The traffic management measures requiring both institutional participation and public acceptance may probably be difficult to implement.

- The occurrence of secondary disasters (fire, traffic incidents) due to main disaster may further impede the transport mobility, transport accessibility, transport safety and transport security. This may demand separate traffic incident management strategies.

An overview on probable disaster impacts on traffic and transport system is given in Table 5-1.

5.3 Traffic and Transport Problems due to Disaster

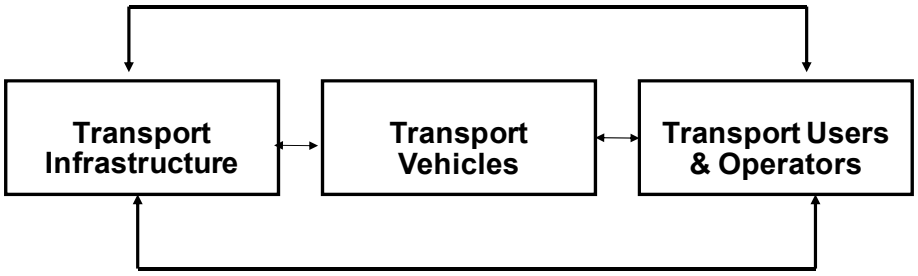


Figure 5-1: Components of transport system

Disaster results in an increase of the traffic demand due to instant requirements of disaster management functions and of the disaster-affected or prone people. The increased traffic demand is often unfulfilled in time due to partial or non-availability of the necessary transport system capacity (Cambridge Systematics 2003; NCHRP 2003; Misra 2004; Litman 2006). In order to fulfil an abrupt increase of traffic demand, a transport system requires transport infrastructure (roads, terminals, traffic control devices), transport modes (high and low capacity vehicles), and transport stakeholders (transport users, transport operators, residents, vehicle manufacturers, etc.). All the three components of transport system are affected by disaster impacts. In the following sections, the disaster impacts on each components of transport system are explained (Table 5-1). Disaster impacts affect the transport system by reducing the capacity of road network, reducing the vehicle performance and by altering the road user behaviour.

The operation of a transport service is dependent on transport infrastructure and modes, together with a set of rules for their operation. Disaster affects surface transport by impacting road network, vehicle performance and by altering the road user behaviour.

Disaster impacts on transport infrastructure

It is important to assess the anticipated impacts of different disasters on transport system due to its crucial role of saving the lives of potential victims by ensuring adequate transport for disaster management functions. The provision of transport infrastructure is particularly important from a transport service point of view in disasters. It is not possible to stock the transport infrastructure supply as it is a transport service and not a transport good. Thus, a transport supply should be provided and consumed where it is needed otherwise its benefit is lost.

Cities rarely escape without at least some physical damage to the transport infrastructure even in highly localised disasters. During disasters, transport infrastructure failures occur through a variety of mechanisms. The vulnerability of transport infrastructure to the impacts of disasters is due to both its vastness and its high degree of redundancy. The literature review on disasters reveals that most disasters affects transport infrastructure and result in the need for transport infrastructure repairs. Investigation of transport infrastructure failures during large urban disasters in the past years reveals the following impacts:

- **Impact on primary road transport infrastructure:** The impact of disaster on primary road transport infrastructure includes all kinds of physical destruction or disruption of road network components. The impacts under this category include road damages (cracking, major settlement, slope collapse, slipping and swelling), road obstructions (debris on road) and road submersion (lane submersion, water logged roads). Such impacts cause direct or indirect reduction in the capacity of roads. The impact on primary transport infrastructure includes impact on highways, bridges, flyovers, culverts, underpasses, overhead footbridges and tunnels. The primary infrastructure is the basic requirement for the movement of people and goods.

Disaster	Geographical Scale	Impacts on Transport Infrastructure		
		Reduced primary road infrastructure capacity	Reduced ancillary road infrastructure capacity	Loss of transport power and communications
TORNADO/HURRICANE	Very large	●	●	●
EARTHQUAKE	Large	●	●	●
TSUNAMI	Very large	●	●	●
FLOODING	Large	●	●	●
VOLCANIC ERUPTION	Small to large	◍	○	◍
WILD FIRES/ FOREST FIRES	Small to large	◍	○	◍
HEAVY SNOW / ICE STORM	Very large	●	●	●
LANDSLIDE/SNOWSLIDE	Small to medium	◍	○	◍
BUILDING FIRE	Small	○	○	○
EXPLOSION	Small to large	◍	◍	●
BUS/TRAIN/AIRCRAFT CRASH	Small to large	○	○	○
NUCLEAR/OTHER RADIATION	Small to large	○	○	●
HAZARDOUS TOXIC RELEASE	Small to large	◍	○	○
CIVIL STRIFE / WAR	Small to large	◍	○	●

Legend:

● **Major impact**

◍ **Moderate impact**

○ **Insignificant or no impact**

Table 5-1: Possible disaster impacts on transport infrastructure

The main traffic and transport problem due to disaster impacts in this category is the reduced road capacity for all transport modes (PT, NMT, IMT and FT)

- **Impact on ancillary road transport infrastructure:** The impact of disaster on ancillary transport infrastructure includes all kinds of physical destruction or disruption of supportive road network infrastructure caused by the disaster. The disaster impacts under this category include damages on terminals, stations, garages, petrol stations and parking spaces. It also includes damages to traffic control devices (static signs & signals) and street infrastructure. It is important to state that damages under this category only comprise non-power and communication damages. The damages to the road markings (also a traffic control device) are included in the above category (impact on primary road transport infrastructure) as damages to the road will mean damage to road markings as well.

The traffic and transport problems in this category are due to inadequate capacity of ancillary road transport infrastructure.

- **Impact on power and communications:** The impact of disaster on power and communications includes all kinds of physical destruction or disruption to power and communication lines and devices such as to traffic control devices and street furniture which is operative on power or communication. It also includes damages to street lights, which are necessary for providing adequate visibility to road users.

The traffic and transport problems are related to inability of traffic information collection and dissemination. The loss of power and communication is critical to traffic management. The TM employs various power and communication devices for traffic control and other purposes. The unavailability of power and communication lead to problems related to inter-agency & inter-modal communications. Power is an important requirement for the operation of power-based transport such as light rail transit, metro and trains and its unavailability cause inadequate transport modes.

Disaster impacts on transport vehicles

The need of extra transport vehicles for fulfilling an additional traffic demand is immediate requirement of disaster management functions. The problem of inadequate transport modes is further aggravated by disaster impact on transport modes.

The disaster impacts on the transport modes include both the disaster impact on vehicle condition and disaster impact on vehicle operation. The disaster impacts the vehicle condition by causing physical damages to the vehicle. The bad weather prevailing before, during or after the disaster in addition to the vehicle condition affects the vehicle operation. The investigation of transport problems pertaining to transport modes reveals vehicles are impacted either due to intrinsic problems (problems related to vehicle) or extrinsic problems of vehicle operation (problems related to poor driving conditions).

- **Impact on vehicle condition:** The disaster impact on vehicle condition includes all kinds of physical destruction or disruption to vehicle that render the vehicle inefficient for further operation. The impacts under this category include vehicle damages related to engines and other parts (non-engine related problems). The impact on the vehicle will vary in type and intensity of impact. Some engine related problems are engine seizure, delayed engine start-up, battery discharge, coolant and air filter related problems. Some non-engine related problems are tyre problems (tyre puncture, tyre burst and tyre under inflation), deposits on vehicle (snow, ice and ash deposits), vehicle vandalism and power and communication loss of transport modes.

The main traffic and transport problem due to vehicle condition in disasters is inadequate transport modes for transport operations.

- **Impact on vehicle operation:** The disaster impact on vehicle operation include disruption in the normal vehicle operations due to bad weather conditions prevailing during disasters. The rain, snow, ice and other slippery agents on roads can reduce pavement friction. Strong winds can blow snow or dust which reduces road visibility. The buffeting of vehicles in storm conditions decreases vehicle stability and control. Thus, impacts under this category include poor vehicle traction control and poor vehicle stability control which reduce the vehicle manoeuvrability and cause reduced vehicle performance during disasters.

The transport problems due to disaster impact on vehicles are inadequate transport modes and reduced vehicle performance for transport operations (see Table 5-2). The reduced vehicle

performance can further result in traffic accidents and affect traffic flow conditions. The capability of a vehicle to traverse successfully on a specific road stretches like terrain, curves, elevated road sections is very complex, particularly during poor road conditions as the characteristics and properties of different types of terrain vary considerably. Thus, poor weather conditions leads to reduced vehicle performance.

Disaster	Geographical Scale	Impacts on Transport Modes	
		Inadequate transport modes	Reduced vehicle performance
TORNADO/HURRICANE	Very large	●	●
EARTHQUAKE	Large	●	○
TSUNAMI	Very large	●	●
FLOODING	Large	●	●
VOLCANIC ERUPTION	Small to large	◍	◍
WILD FIRES/ FOREST FIRES	Small to large	○	◍
HEAVY SNOW / ICE STORM	Very large	●	●
LANDSLIDE/SNOWSLIDE	Small to medium	◍	◍
BUILDING FIRE	Small	○	○
EXPLOSION	Small to large	◍	○
BUS/TRAIN/AIRCRAFT CRASH	Small to large	●	○
NUCLEAR/OTHER RADIATION	Small to large	○	○
HAZARDOUS TOXIC RELEASE	Small to large	○	◍
CIVIL STRIFE / WAR	Small to large	◍	○

Legend:

● **Major impact**

◍ **Moderate impact**

○ **Insignificant or no impact**

Table 5-2: Possible disaster impacts on transport modes

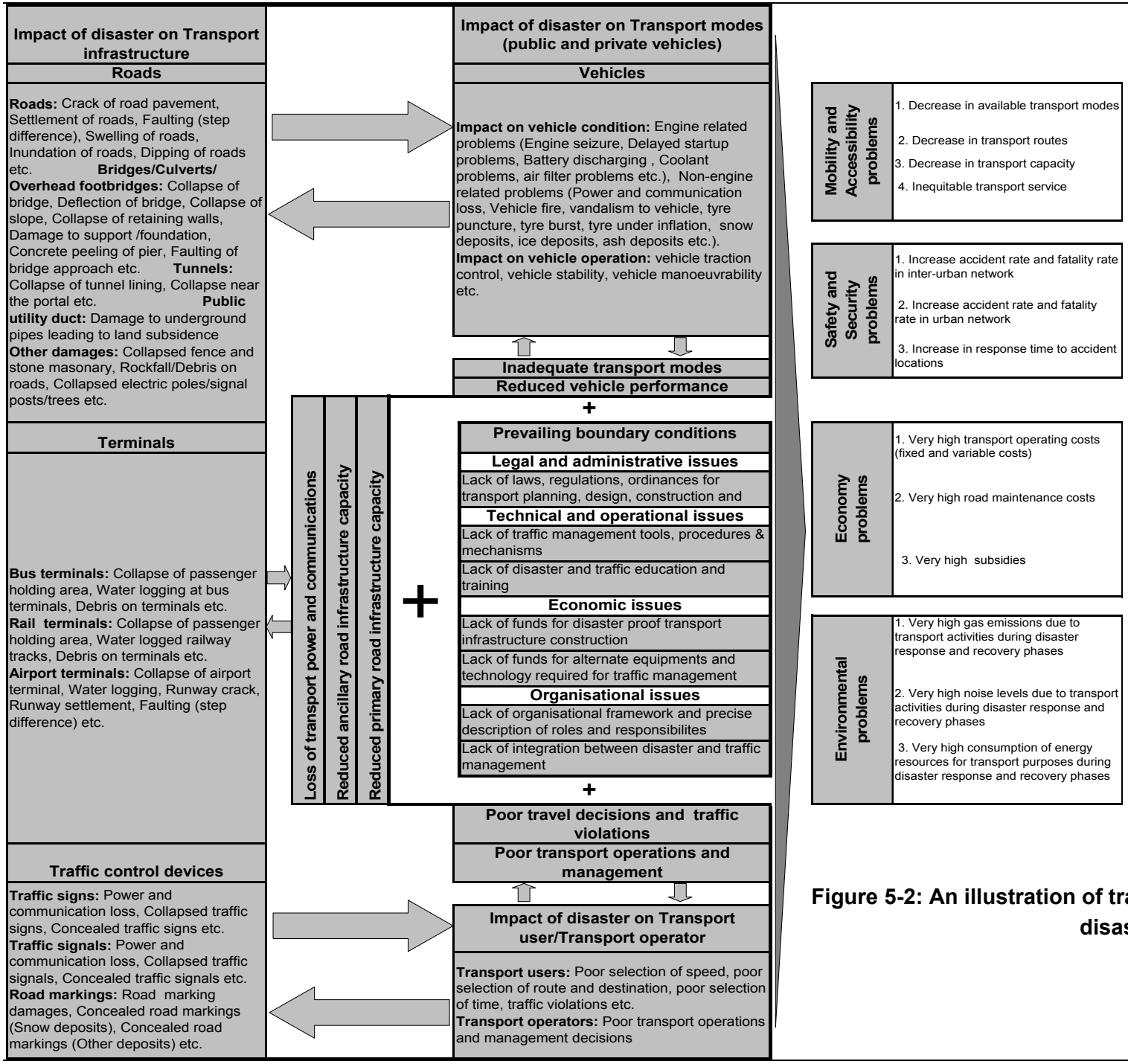


Figure 5-2: An illustration of traffic and transport problems in disasters

Table 5-3: Possible disaster impacts on transport system components

Disaster	Geographical Scale	Probable disaster impacts on				
		Routes	Modes	Terminals (Bus terminals, rail terminals and airports)	Control Devices	Driving conditions
TORNADO/HURRICANE	Very large	Submersion of roads (water)	Damage of vehicles (water)	Submersion of terminals (water)	Damage of traffic control devices (submersion, power failure)	Poor driving conditions (Poor visibility, slippery roads, poor traffic information)
EARTHQUAKE	Large	Damage of roads (debris)	Damage of vehicles (physical damage)	Damage of terminals (structural failure)	Damage of traffic control devices (physical damage, power failure)	Poor driving conditions (Poor condition of roads, poor traffic information)
TSUNAMI	Very large	Submersion of roads (water)	Damage of vehicles (water)	Submersion of terminals (water)	Damage of traffic control devices (submersion, power failure)	Poor driving conditions (Poor visibility, slippery roads, poor traffic information)
FLOODING	Large	Submersion of roads (water)	Damage of vehicles (water)	Submersion of terminals (water)	Damage of traffic control devices (submersion, power failure)	Poor driving conditions (Poor visibility, slippery roads, poor traffic information)
VOLCANIC ERUPTION	Small to large	Damage of roads (ash)	Damage of vehicles (fire,ash)	Damage of terminals (fire,ash)	Damage of traffic control devices (ash deposits, smoke)	Poor driving conditions (Poor visibility, poor traffic information)
WILD FIRES/ FOREST FIRES	Small to large	Damage of roads (ash, smoke)	Damage of vehicles (fire,ash)	Damage of terminals (fire,ash)	Damage of traffic control devices (ash deposits, smoke)	Poor driving conditions (Poor visibility, poor traffic information)
HEAVY SNOW / ICE STORM	Very large	Damage of roads (snow, black ice, fog)	Damage of vehicles (cold temperature)	Damage of terminals (snow, black ice, fog)	Damage of traffic control devices (snow deposits, fog)	Poor driving conditions (Poor visibility, slippery roads, poor traffic information)
LANDSLIDE/SNOWSLIDE /AVALANCE	Small to medium	Damage of roads (debris)	Damage of vehicles (debris)	Damage of terminals (debris)	Damage of traffic control devices (mud/snow deposits, dust)	Poor driving conditions (Slippery roads, poor traffic information)
BUILDING FIRE	Small	Damage of roads (ash, smoke)	Damage of vehicles (fire.ash)	Damage of terminals (fire, ash, high temperature)	Damage of traffic control devices (ash deposits, smoke, physical damage)	Poor driving conditions (Poor visibility, poor traffic information)
EXPLOSION	Small to large	Damage of roads (ash, smoke)	Damage of vehicles (fire,ash)	Damage of terminals (fire, ash, high temperature)	Damage of traffic control devices (ash deposits, smoke, physical damage)	Poor driving conditions (Poor visibility, poor traffic information)
BUS/TRAIN/AIRCRAFT CRASH	Small to large	Damage of roads (ash, smoke)	Damage of vehicles (fire,ash)	Damage of terminals (debris, chemicals)	Damage of traffic control devices (ash deposits, smoke, physical damage)	Poor driving conditions (Poor visibility, poor traffic information)
NUCLEAR/OTHER RADIATION	Small to large	Unknown	Unknown	Unknown	Unknown	Unknown
HAZARDOUS TOXIC RELEASE	Small to large	Damage of roads (chemicals)	Damage of vehicles (chemicals)	Damage of terminals (chemicals)	Damage of traffic control devices (chemical release)	Poor driving conditions (Slippery roads, poor traffic information)
CIVIL STRIFE / WAR	Small to large	Damage of roads (obstruction)	Damage of vehicles (intentional physical damage)	Damage of terminals (intentional physical damage)	Damage of traffic control devices (intentional physical damage)	Poor driving conditions (Poor condition of roads, poor traffic information)

Disaster impacts on transport users and operators

The disaster impacts on transport users include road users (IMT drivers, passengers, cyclists, pedestrians), PT drivers and transport operators. Transport drivers and operators are required for transport service operation and traffic control operation during disasters. Transport service operations include activities such as frequency of operation, scheduling, control and supervision of vehicles and road maintenance.

The disaster impacts are limited to poor decision-making behaviour of individuals, institutions and communities. It is very important to assess the disaster impacts on people. The psycho-physiological and other disorders are common in disasters which cause poor rationality among road users, drivers and operators. Since the sound psycho-physiological state is required for the operation of transport service and traffic control operations, this problem is very important.

The impacts of the disaster on transport users vary owing to disaster type and disaster intensity. Literature review on investigation of road user behaviour during disasters indicated poor decision-making behaviour (poor rationality and maladaptive behaviour). A “disaster syndrome” characterise the condition of many road users, drivers and operators. The study of psycho-physiological disorders in general public, road users, drivers and operators does not belong to the domain of traffic management, although poor decision-making is observable. The disaster impacts on the transport users and transport operators are explained below.

- **Impact on transport user:** The disaster impact on transport users include all kinds of behavioural disorders that affect the decision-making behaviour and display abnormal behaviour. By the definition of abnormal behaviour, any deviation from the established traffic management rules and regulations is considered as an abnormal behaviour. It is difficult to predict the normal behaviour due to unpredictable impacts of disasters on transport system. Disaster impact people decision-making which cause poor selection of speeds, routes, destinations and modes by the transport user which accounts for poor travel decisions and high incidence of traffic violations.

The main traffic and transport problem due to poor decision-making is the high incidence of traffic violations. Traffic violation is considered as any decision which does not conform to the pre-recognised or situation-imposed set of traffic rules.

- **Impact on transport operator:** The disaster presents some unprecedented traffic situations for transport operators and hence operators face a lot of decision-making problems. In the absence of any policy document on traffic and transport operations, the traffic situation is worsened. In such an event, transport users are left to take several decisions related to traffic operations without proper instructions or procedures on transport routes, scheduling of operations, traffic speeds, frequency of operations, prioritisation and optimisation of operations by the traffic and transport operators. The poor decision-making in traffic and transport operation cause counter- productive operations.

The main traffic and transport problem due to poor rationality and maladaptive transport operator behaviour is the poor transport service and traffic control operations (see Table 5-4).

The poor travel decisions as well as poor traffic and transport operations cannot be validated. Such decisions indicate the deficiency in the level of preparedness of different transport users and operators. This is primarily due to a lack of instructions and procedures on road user behaviour

and traffic operations during disasters. Thus, there is a need to design instruction manuals for various disasters suggesting the desired road user behaviour and expected traffic operations.

Disaster	Geographical Scale	Impacts on Transport User/Operator	
		Poor travel decisions and traffic violations (Transport user)	Poor transport operations and management (Transport operator)
TORNADO/HURRICANE	Very large	●	●
EARTHQUAKE	Large	●	●
TSUNAMI	Very large	●	●
FLOODING	Large	●	●
VOLCANIC ERUPTION	Small to large	◍	◍
WILD FIRES/ FOREST FIRES	Small to large	●	◍
HEAVY SNOW / ICE STORM	Very large	◍	●
LANDSLIDE/SNOWSLIDE	Small to medium	◍	◍
BUILDING FIRE	Small	◍	◍
EXPLOSION	Small to large	◍	●
BUS/TRAIN/AIRCRAFT CRASH	Small to large	◍	●
NUCLEAR/OTHER RADIATION	Small to large	●	●
HAZARDOUS TOXIC RELEASE	Small to large	●	●
CIVIL STRIFE / WAR	Small to large	●	●

Legend:

● **Major impact**

◍ **Moderate impact**

○ **Insignificant or no impact**

Table 5-4: Possible disaster impacts on transport user and transport operator

5.4 Traffic and Transport Problems due to Prevailing Boundary Conditions

The problems in this category are external to the disaster impact and include problems due to prevailing boundary conditions of disaster-affected or disaster-prone areas. It is explained in the earlier chapters that a disaster is an outcome of a hazard in vulnerable conditions. The poor transport development state increases the vulnerability of the habitats to the impacts of hazards. The various development states that account to the vulnerable conditions are explained in Figure 2-1. This section reviews the vulnerabilities with respect to transport in disasters. The various underlying causes of vulnerabilities have been grouped as legal and administrative issues, technical and operational issues, economic issues and organisational issues. These issues have been derived form several literature and disaster-area studies. These issues form the boundary conditions of disaster-affected or disaster-prone area in context to traffic management. The boundary condition provides an orientation to the disaster traffic management. The issues explained in this section provide a rationale for the development and implementation of TM measures.

Legal and administrative issues

Lack of laws and legal framework

The legal and administrative issues include the lack of laws, regulations, ordinances and legal framework. The literature revealed a lack of proper legislation, proper policies and a framework for transport planning, transport design, transport infrastructure construction and traffic management for disaster situations (NCHRP, 2003; PIARC, 1995). This issue is an important issue due to its direct implication on transport accessibility, transport mobility, transport safety, transport economics and environmental quality. The consequences of this issue on transport are observable on traffic violations by transport users. Similarly transport operators lack the standard operating procedures and legal guidelines which result into ineffective traffic management.

Technical and operational issues

The technical and operational issues include the lack of standard operating procedures (SOP), lack of equipments and lack of training. The following issues are discussed in the following sections.

Lack of standard operating procedure

The current literature fails to describe the standard operating procedures for traffic management in disasters. The traffic management in disasters lacks the understanding of technical and operational procedures of traffic management for disaster response and recovery functions involving medical care, disaster control and other disaster management functions (C.Goodwin 2002; Minhans 2006). The non-existence of priorities and action plan leads to concentration and duplication of activities related to traffic management. The lack of procedures is also responsible for untimely or delayed activation of traffic management.

Lack of equipments

Lack of adequate and proper equipments for traffic control in disasters is a traffic management issue. The equipments implementable for daily traffic control often do not function in disasters. The unavailability of power and communication for the operation of traffic information and control systems is observable in disasters. Furthermore the unavailability of power causes in-operation of some transport modes (power-based transport modes). Due to dependence on power and communications, adequate and proper equipments are pre-requisite for implementing traffic management measures.

Lack of training

Traffic management is undeveloped and untrained for disaster situations. Traffic responders such as public and private transport operators are often untrained to operate in disaster conditions due to inadequate knowledge on disasters and the processes of disaster management. This reveals the inability to activate and implement the right traffic management measures for unpredictable disasters (terrorist attacks, earthquake) which demand quick decision-making for providing assistance related to medical care and disaster control. Moreover the traffic management is not cross-trained to provide TM assistance to other forms of transport (air and water transport).

Economic issues

Lack of economic resources

The economic issues related to transport are lack of economic resources for the operation of required transport services. In general the financial constraints pose a big threat to traffic management more specifically in disaster-prone poor countries. Such a deficit of economic

resources and lack of subsidies affects the transport infrastructure design, construction, maintenance and operation by constraining safe design, construction, maintenance and operation of transport system. This leads to the adoption of unsafe practices of transport construction and maintenance which contributes to vulnerable transport conditions. Traffic management in disasters requires alternate equipments and technology to ensure effective transport operations. Many underdeveloped and undeveloped countries do not have access to state-of-the-art traffic management equipments and technology and under such circumstances the traffic is poorly managed in disasters.

Organisational issues

Lack of organisation

The organisational issues include the lack of organisation of traffic management. Lack of organisation includes social, political and administrative organisation. This issue includes both lack of stakeholder's participation and lack of organisational structure.

The organisational issues create problems of integration and coordination among different stakeholders (Ministry of Internal Affairs 2002; NDMD 2004). In disasters, traffic management involves various stakeholders such as road maintenance authorities, disaster management authorities and transport users. The poor coordination of the traffic management authorities and disaster management authorities is due to organisational differences and evasion of tasks (Pisano, Goodwin et al. 2002). Traffic management currently is not considered a part of an active disaster management in many disaster management plans (DDMA, 2002; DDMP, 2004). As a result traffic management authorities are uninformed about the state of the practice of disaster management operations, their orientation and priorities. Coordination and integration problems of DM and TM stakeholders cause inadequate mobilisation of scarce resources.

Due to undefined roles and responsibilities of TM stakeholders, the traffic management lacks the chain of command. The absence of an organisation structure often causes coordination problems among multiple agencies and jurisdictions. These issues result into non-implementation of TM measures even when resources to implement exist.

5.5 Summary

This chapter provided the traffic and transport problems and issues in disasters. The categorisation of the causes of problems and issues provides necessary areas of transport sectors. The disaster impacts on transport infrastructure are observable to reduce capacities or roads, terminals and other traffic control devices. Similarly the disaster impacts on transport modes are observable to reduce the availability of transport modes and their performance. The disaster impacts on transport users are observable on poor travel decisions and traffic violations. The poor decision-making results in poor transport service and traffic operations. Four issues were discussed which increases the vulnerability of regions to hazards. The legal and administrative issues revealed lack of laws and legal framework. The technical and operational issues revealed lack of SOP, equipments and training for traffic management. The economic issues revealed lack of economic resources and subsidies in disaster-affected or disaster-prone region. The organisation issues revealed lack of organisation which cause coordination and implementation problems during disasters. The understanding of traffic and transport problems and issues provide the orientation of traffic management operational framework for disasters in the next chapter.

6 Traffic Management Operational Framework for Disaster Management

6.1 Introduction

Transport enhances the quality of life and economic prosperity by connecting people, communities, employment, goods, services and amenities. The importance of the effective transport services is recognised by many governments and for attaining multiple interdisciplinary objectives. Many urban planners formulate visions, mission statements, goals and objectives of transport to provide a framework for managing transport operations. An important objective of the effective governance and administration is to provide adequate safety and security to the people in disasters. An effective form of governance formulates disaster management policies, acts, and other forms of legislations to address the needs of safety and security of their people during disasters. In some countries, the current disaster management is quite unplanned due to lack of operational framework of many multidisciplinary areas involved in disaster management process including traffic management. The literature review has revealed the lack of systematic approaches in the implementation of traffic management in cases of disasters. This is primarily due to the lack of complete understanding about the impacts of disasters on transport system and an inadequate knowledge on how to use the potential of traffic management to ensure resiliency of the transport system even in the cases of disasters.

In this chapter, a traffic management operational framework for its application in disaster situations is presented (Figure 6-1). The traffic management framework serves as an effective decision-making tool for a dynamic process of planning, design and implementation of traffic management. The purpose of this chapter is to describe and present the future vision and mission statements of traffic management in cases of disasters. The traffic management goals and objectives are also formulated and presented in this chapter.

6.2 Vision Statement

Every natural system or engineered system serves some purpose within the systems hierarchies. In some cases, this purpose can be fairly self-contained and focused on only a small role in the hierarchy. In other cases, a particular system could be an important component in the effective functioning of the other systems. A transport system can be considered for both cases. One perspective of transport system is focused on the transport functions, which aims at providing the mobility and accessibility to the people. Another perspective of transport system is the performance of transport system for supporting other systems or system functions for example security, environment or economy functions (DMF) during disasters. Thus, transport system supports the activities of other systems or system functions as well as being itself a source of negative impacts on environment, safety and economy.

A fundamental component for achieving sustainable development of urban cities is the existence of a clear and shared vision of cities, which provides both the framework and the impetus for the future development of the cities. Over the last few years, there is a growing concern about the safety of the cities in cases of disasters. The increasing number and type of natural and manmade disasters are constantly making difficult for planning, policy and design models to respond effectively. This fact provides challenges to stakeholders of disaster management. The issues of disaster management (discussed in earlier chapters) also pose challenges to sustainability of local approaches of city design and governance to disasters. The statement of vision contributes to the

development of a thematic framework by articulating the concept and content of urban sustainability. One of the original descriptions of sustainable development is credited to the Brundtland Commission: "**Sustainable development is defined as a development process that provides the needs of the present generation without distracting the needs of future generations**" (World Commission on Environment and Development, 1987). The process of disaster management promotes the sustainability issues by ensuring the needs of the society in terms of food, housing and medical care among several other societal functions. A vision is generally presented as interaction between the desired states of prosperity, environmental quality and social quality of life. This interaction is mostly observed and presented as a strongest link to sustainable development.

In the city planning context, vision portrays the future imagination of a city. The vision statement of traffic management for most cities supports the city vision concept of enhancing the quality of life and economic prosperity by connecting people, communities, employment, goods, services and amenities. The context of enhancing the quality of life is too general and it encompasses several themes including the city preparedness for disasters. The literature indicates that the vision statements of cities are expressed using different themes to describe the desired end states. Such themes are **capable city**, **ideal city**, **learning city**, **livable city**, **planned city**, **resilient city**, **safe city**, **youth friendly city**, **bicycle city** etc. (Axworthy, Fallick et al., 2006). These visions are generally the key visionary themes in most of the city planning and development. Vision sometimes encompasses a lot of themes together and yet depicts the specific characteristic or quality of a city. Some planners expressed the vision of a livable city to include most specific visionary themes of the city e.g. **motorcycle dependent cities** (Khuat, 2006; Timmer and Seymoar, 2006).

The vision of a safe city is generally addressed in many key visionary themes like **resilient city**, **capable city**, **livable city**, **crime-free city**, **disaster-resistant cities**, **disaster-resilient cities**, etc. Traffic management supports disaster management by implementing proactive and reactive strategies in disasters. Thus, traffic management supports the vision of disaster resistant cities by providing the efficient traffic and transport operations to minimise the impact of disaster on the community. Thus, the vision of traffic management as an aspect of disaster management should be formulated. One such formulated vision is: ***"ensure the safe, quick and efficient movement of people and goods on the transport system, irrespective of any disaster"*** (Minhans, 2004).

The vision can consist of general statements of the desired end states or can be as specific as a well-defined scenario. The vision can be of a state, an organisation or of local businesses. The vision statement indicates the interests of the organisation who forms it. Vision may represent the majority decision of a community, organisation or nation's programmes. Many authors use the terms secure city, safe cities, and resilient cities in their vision statements to provide similar development concepts for the disaster prone city. In either case, the vision of a disaster-prone city is formulated to develop the city's resistance to the impact of disasters.

6.3 Mission Statements

The mission statements describe the purpose of the vision for being in existence or in other words the vision supports a certain mission. The mission statement describes the limits or boundaries within which the vision is achieved. The formulated mission statements of traffic management in cases of disasters are:

- **preserve the societal values**,
- **preserve the natural and built-up environment**, and

- **preserve the economics of the disaster-affected region**.

The mission statements of disaster traffic management indicate the use of acceptable or compatible traffic measures. The mission statement of traffic management addresses the sustainability issues of the society, environment and the economy. In the absence of standardised goals of disaster traffic management, the mission statements address at least three major areas of consideration; one area of consideration is preserving the societal values. The other areas of consideration are conserving the natural resources by reducing the environmental impacts, and improving the economic reliability and economic system operations related to transport.

6.4 Goals of Disaster Traffic Management

In order to realise the vision, one must think about mechanisms and procedures available to attain the vision. The goals, objectives, strategies, and performance targets are the instruments in achieving a desired vision. Most city authorities initially develop citywide goals from the inputs provided by the Community and the State's obligation to the community. The vision and mission statements of disaster traffic management provide the orientation for the achievement of the traffic management goals and objectives.

The TM orientation is derived from the shortfalls, issues, problems and states of traffic management in cases of disasters. Sometimes these issues may not be only transport related. Literature review on disasters and traffic management has consistently indicated the need for transport mobility, transport accessibility, transport safety, transport security, traffic education, transport economy and transport environment, as the main requirements of traffic management. In some publications, traffic management goals are formulated statements indicating the need to increase the efficiency, integration and productivity of transport. The efficiency, integration and productivity goals of traffic management are well considered in this study for achieving the mobility and safety goals of traffic management in disasters. In most literatures on disaster traffic management, the economic and environmental goals are inadequately addressed. This is primarily due to certain degree of trade-offs with the other objectives such as mobility, accessibility, safety, etc. The proposed operational framework in this chapter adequately addresses the relevance of both the economic and environmental goals of traffic management in cases of disasters.

This study proposes four basic goals of disaster traffic management, which are:

- **ensure the quick accessibility and adequate mobility of transport in disasters**,
- **ensure the safety and security of transport in disasters**,
- **ensure the economy of the transport system operations in disasters**, and
- **reduce the impact of transport on environment in disasters**.

This formulation of the goals and objectives served as a guide for the development of traffic management measures in the later chapters.

6.5 Objectives of Disaster Traffic Management

The TM objectives are specific and measurable statements, which relate to the fulfilment of the set TM goals. Transport is an important medium to satisfy the disaster management goals and descendent objectives. On the other hand, traffic management is important tool to attain the transport goals in cases of disasters. The above mentioned four set goals of traffic management support the functions of disaster management by providing efficient transport system during disasters. The descendent objectives of each goal of traffic management are described in the next

sections. The descendent objectives exhibit interrelationships within different TM goals. The formulation of TM objectives of a goal considered the possible conflicts of one objective on the other goals.

Transport accessibility and mobility objectives of traffic management

Accessibility is a term which has been defined and measured in a variety of ways and is often used in the field of transport in various urban, regional and rural contexts. Accessibility is the ability to reach the desired goods, services, activities and destinations. Access is the ultimate goal of transport and transport systems may be evaluated on their ability to provide access. Mobility is the ability to travel and is described with the physical movement, including travel by walking, cycling, public transit, taxi, private automobile and other motorised modes. The mobility refers to the ability to travel and travel is a term used in transport context as the mobility fulfilled. Mobility includes the provision of transport services based on places and time of demand, information required for the trips, and the ease and costs involved in using a transport facility. Mobility differs from accessibility in the fact that one can even have mobility and yet no accessibility for example availability of adequate transport modes or affordability of transport does not mean accessible destinations. The increase of the travel opportunities does not necessarily allow a greater ability to reach destinations beyond the short term because increasing mobility is sometimes associated with deteriorating accessibility (Litman, 2005, Simpson, 2005).

The impact of disaster is clearly observable on inadequate mobility due to increasing delay, reducing traffic volume, decreasing capacity, decreasing speed, and disintegrating transport modes. The physical damage to the roads following the disaster, impacts the accessibility by reducing the capacity & reducing the number of routes to reach destinations including disaster-affected areas. Thus, enhancing mobility means maximising the transport and travel opportunities whereas improving accessibility is focused on increasing the number of accesses or routes. This objective considers both the accessibility aspects and the mobility aspects with regard to disaster traffic management (See Table 6-1).

Objective 1: Provide the equitable transport service

This objective ensures provision of transport services to:

- **mobility-disadvantaged people**,
- **inaccessible and low accessibility areas**, and the equitable use of
- **transport modes**.

This objective ensures the equity of transport service regardless of physical disabilities, education disabilities and personal disabilities of different people. Transport equity means the equitableness with which the transport benefits and transport costs are distributed. Equitable transport services will treat everyone equally, regardless of socio-economic factors as ethnicity, gender or income. This objective deals with vertical equity, which is concerned with the distribution of transport benefits and costs among individuals and groups who differ in abilities and needs due to socio-economic reasons. The measures of the equity objective are oriented towards compensating the inequities of transport so disadvantaged groups do not bear an excessive share of the external costs of traffic pollution, traffic accident risk and transport costs. The experiences from Hurricane Katrina indicated the failure to provide the evacuation for some people such as old people, people with disabilities, African-American people, etc. (Litman, 2006). Thus, the equity objective enhances the mobility by providing equal priorities and opportunities with respect to a particular

transport service. The transport equity objective also deals with the equitable use of transport modes, except for necessary traffic restrictions on individual motorised transport and freight transport at different routes, destinations and times. The equitable transport objective is measurable by such indicators as fare structure, tax burdens due to subsidy, transport service quality, travel opportunities, etc. and are expressed in per capita, per kilometre, per person-kilometre, per trip, per peak period and per tax subsidy. The social costs borne by the transport organisations per person-kilometre and subsidy per person-kilometre are common criteria to measure the equity of transport.

Objective 2: Increase the number of transport route options

This objective focuses on increasing the transport route options in order to increase the accessibility to important destinations. The measures of this objective include the development of well connected, safe and efficient pedestrian, bicycle and motorised transport routes for respective transport destinations. This includes the use of secondary transport network to increase the possibilities of reaching the accessibility-threatened disaster area. Although, the fulfilment of this objective requires infrastructure measures, yet this objective is typically confined to the establishment of new routes or to extension of existing routes, and the re-routing of flexible transport routes only. The establishment and development of missing links are proposed for the fulfilment of this objective. The criteria to measure this objective are the number of routes or links available per required destination, travel time, travel distance and per transport mode.

Objective 3: Increase the number of transport mode options

This objective intends to enhance mobility by providing multiple transport modes to create a flexible, demand-responsive transport system in disasters. The objective of increasing transport mode option includes measures which increase the transport fleet of one or more transport modes. In the formulation of this objective, the possibility to fulfil the increased traffic demand in disasters is considered. Thus, the given objective is measured as number of mode choices per trip for different trip purposes.

Objective 4: Increase the capacity of the transport system

Under this objective the increase of the capacity of transport system in disasters is considered. This objective involves the improvement of both transport infrastructure and transport operation in order to enhance the transport capacity. This includes increasing the infrastructure capacities of roads and ancillary infrastructure such as parking, garages, bus stations and other road transport infrastructure. This objective also includes increasing the operation capacities of a particular transport service by increasing the frequency of operations, time of operations, etc. Under this objective, the increase of infrastructure capacities is limited to existing infrastructure possibilities only. New development is normally not considered due to limited availability of funds and time for construction. In the cases where full infrastructure capacity cannot be achieved, this objective will aim to provide the basic infrastructure. This objective could be measured through transport infrastructure capacities e.g. road length, number of bus stations, parking area, etc. and traffic operation capacities e.g. frequency of traffic operations, start and end time of traffic operations, etc.

Transport Accessibility & Mobility Objectives	Possible Traffic Management Strategies	Type of Strategy	Approaches
To provide the equitable transport service	Strategy to improve the transport supply capacity	Transport Supply Augmentation	• Increase the user friendliness of the transport services
			• Personalise the public transport services
			• Provision of services for immobile transport user groups
			• Use of equitable modes through road improvements
	Strategy to shift the use of individual motorised transport	Traffic Demand Reduction	• Use of equity promoting public transport services
			• Use of equity promoting individual motorised transport services
To increase the number of transport route options	Strategy to improve the transport supply capacity	Transport Supply Augmentation	• Expand or modify fixed routes
			• Development of missing links for all modes
			• Development of routes for bicyclists and pedestrians
	Strategy to shift the use of individual motorised transport	Traffic Demand Reduction	• Use of established bicycle and pedestrian routes
			• Use of high capacity lanes (bus lanes, HOV lanes)
To increase the number of transport mode options	Strategy to improve the transport supply capacity	Transport Supply Augmentation	• Generate more transport modes through special agreements
			• Generate more transport modes (carpooling)
			• Generate more transport modes (inter-operable transport)
			• Generate more transport modes (procure company vehicles)
			• Establish transport routes for NMT modes
	Strategy to improve integration between traffic-related activities		• Improve integration of transport modes
			• Improve inter-operability of transport modes
	Strategy to avoid or reduce unnecessary car-based mobility	Traffic Demand Reduction	• Decrease the use of IMT modes
			• Promote high capacity modes of IMT
	Strategy to increase the vehicle utilisation of transport modes		• Promote high capacity modes of PT
			• Establish high capacity lanes
	Strategy to shift the use of individual motorised transport		• Shift car based mobility to public transport mobility
			• Shift car based mobility to non-motorised transport mobility
To increase the capacity of the transport system	Strategy to improve the transport supply capacity	Transport Supply Augmentation	• Create new capacities (road network and section control)
			• Provide supportive infrastructure (gas stations, repair shops)
	Strategy to improve integration between traffic-related activities		• Improve integration to optimise infrastructure capacities
			• Improve integration to optimise transport operation capacities
	Strategy to reduce the disturbances of traffic flow		• Improve traffic flow conditions (traffic signal coordination)
			• Improve traffic flow conditions (road geometric modifications)
	Strategy to avoid or reduce unnecessary car-based mobility	Traffic Demand Reduction	• Promote tele-substitutions (teleworking, teleshopping)
			• Decrease the single occupancy trips using IMT modes
	Strategy to increase the vehicle utilisation of transport modes		• Promote high capacity modes of IMT
			• Promote high capacity modes of PT
	Strategy to shift the use of individual motorised transport		• Shift traffic to PT
			• Shift traffic to NMT
	Strategy to improve the spatial distribution of traffic volume		• Enforce rules and regulations to control traffic at certain locations
	Strategies to improve the temporal distribution of traffic volume		• Enforce rules and regulations to control traffic during certain time periods

Table 6-1: Traffic management strategies for accessibility & mobility objectives

Transport safety and security objectives of traffic Management

Disaster affects road safety through increased accident risk both in terms of accident frequency and accident severity. Many articles of academic literature document safety issues in disasters, weather events and special events (Cambridge Systematics, 2003; NCHRP, 2003; USDOT, 2003; Litman, 2006). The occurrence of traffic accidents is highly related but not limited to: **prevalence of poor weather and road conditions during or after disaster**, and **prevalence of secondary disasters following a primary disaster e.g. power grid failures, earthquake, fires, etc**.

The following section describes the formulated safety and security objectives of disaster traffic management (see Table 6-2):

Objective 1: Reduce the response time in traffic and other accidents

The objective of reducing the response time is formulated to accelerate medical response in traffic-related accidents or in other accidents. This objective is evaluated based on both the response time to reach the accident location and to reach the hospital or safe location. This objective is applicable for all traffic and non-traffic accidents such as fire, explosions among other accidents

which may or may not be traffic related. The fulfilment of this objective may involve complimentary measures that improve traffic flow conditions and hence contribute to the response time reduction. The traffic incident management is aimed at reducing the response time by reducing the individual time components e.g. **detection time**, **information time**, **verification time**, **registration time**, **decision time** and **travel time to the accident site**. Thus, the measures belonging to this objective are intended to reduce either one or many individual time components to minimum.

Objective 2: Reduce the number of traffic accidents

The objective of accident reduction is aimed at reducing the number of traffic accidents of transport modes used in disaster response and recovery operations. The objective considers all possible factors that cause traffic accidents and propose measures for improving either one or many factors. The factors that cause traffic accidents are:

- **road condition**,
- **vehicle condition**,
- **driver condition**,
- **road users**, and
- **environmental conditions**.

The accident reduction objective is clearly measured by estimating the reduction in number of accidents, which is expressed as accidents per vehicle population, accidents per unit population and accident density measured as accidents per kilometre of road length.

Objective 3: Reduce the severity of traffic accidents

The objective of accident severity reduction is aimed at reducing the fatality of accidents and thus increasing the chances of the survival of accident victims. The fatality of traffic accidents is also dependent on factors related to driving conditions e.g. speed differentials and heterogeneous traffic flow conditions among other factors given in the earlier objective. The measures belonging to this objective also propose the prior protection of crucial transport properties from damages. This objective is measured by estimating the reduction in fatality of accidents e.g. number of deaths per unit vehicle population, fatalities rates per year, total costs of property damage per accidents, etc.

Traffic Safety and Security Objectives	Possible Traffic Management Strategies	Type of Strategy	Approaches
To reduce the response time in traffic and other accidents	Strategy to improve the transport supply capacity	Transport Supply Augmentation	• Improve information collection and dissemination techniques
			• Improve road conditions (visibility, road geometry and others)
			• Better traffic education and training
	Strategy to improve integration between traffic-related activities		• Improve integration to optimise infrastructure capacities
			• Improve integration to optimise transport operation capacities
	Strategy to reduce the disturbances of traffic flow		• Improve traffic flow conditions (green wave) for general traffic
			• Provide emergency vehicles priority (vehicles pre-emption)
	Strategy to improve the spatial distribution of traffic volume	Traffic Demand Reduction	• Re-route the incoming traffic on other routes
			• Provide special routes for emergency vehicles
To reduce the number and severity of traffic accidents	Strategy to reduce the traffic accidents and its impacts	Transport Supply Augmentation	• Improve road conditions (visibility, road geometry and others)
			• Improve vehicle conditions (tyre chains, reflectors and others)
	Strategy to reduce the disturbances of traffic flow		• Better traffic education and training
			• Reduce potential conflicts (transport modes segregation)
			• Provide information about anticipated road conditions
	Strategy to shift the use of individual motorised transport	Traffic Demand Reduction	• Shift IMT to PT by ensuring safer PT modes and routes
			• Shift IMT to NMT by ensuring safer NMT modes and routes
	Strategy to improve the spatial distribution of traffic volume		• Shift traffic to safer routes
			• Shift traffic to safer destinations
	Strategies to improve the temporal distribution of traffic volume		• Ensure time slots for freight traffic
			• Ensure time segregation of other conflicting traffic

Table 6-2: Traffic management strategies for traffic safety objectives

Transport economy objectives of traffic management

Most disasters cause major damages to transport system components (roads, vehicles and road users) affecting the traffic operations, which leads to significant economic disruption (E.Chang and Nojima, 1999). On the other hand, disaster response and recovery phases of disaster management demand for additional cost-intensive traffic operations. Thus, the consideration of sustaining the economy of traffic operations during disasters is of paramount importance as disaster traffic operations are cost-intensive and severely impact the overall economy of the disaster affected region. Therefore, traffic management in cases of disasters need to support the economic goals of disaster management by optimising the traffic operations during disasters. Traffic management implementation bears the potential to reduce the total transport costs (including fixed and variable costs) and to maximise the benefits of the traffic operations. This section describes the formulated economic objectives of disaster traffic management which are (refer Table 6-3):

Objective 1: Reduce the total transport costs

This objective focuses on reducing the total transport costs. The total transport costs include the cost of the initial facility, cost of maintenance of facility and the road user costs. The road user cost is composed of the following:

- **vehicle operating costs**,
- **travel time costs**, and
- **accident costs**.

Although this objective is intended to reduce the total transport costs, the emphasis is required on providing traffic management measures which reduce the road user costs, especially the vehicle operating costs (both the fixed and variable costs). This objective considers administrative and organisation measures to reduce the fixed costs e.g. charges related to insurance, maintenance, finance, licensing and registration. In addition, the measures of the objective are aimed to reduce the variable cost (fuel and oil costs, fuel taxes, tolls and parking costs, cost of automobile parts, and other related costs) involving promotion of non fuel-based transport, reduction of trips and shifting of trips among other measures. This objective is measured generally as operating cost per unit capacity. They are also expressed as total cost per person-kilometres for passenger transport, total cost per ton-kilometres for freight transport, total costs per activity, etc.

Objective 2: Maximise the economic efficiency of existing transport systems

This objective focuses on increasing the offered benefits of the existing transport systems. The objective of maximising economic efficiency is applicable for different transport modes e.g. public transport, individual motorised transport, etc. The economic efficiency benefits of a particular transport system are vehicle operating costs savings, congestion reduction savings, parking costs savings, road infrastructure maintenance costs savings, accident costs savings, fuel consumption savings, etc. The economic efficiency is generally measured in cost savings, travel time savings, accident costs savings. Efficiency considers the time, cost and effort required to produce a certain benefit. This objective ensures the maximum passenger or freight transport within the minimum time, costs and capacity limits. Time is one criterion to measure this objective, which is expressed in average time taken per passenger-kilometres or tonnes kilometres. Others are costs/person/km, costs/tonne/km, etc.

Transport Economy Objectives	Possible Traffic Management Strategies	Type of Strategy	Approaches
To reduce the total transport costs	Strategy to improve the transport supply capacity	Transport Supply Augmentation	• Improve traffic flow conditions (traffic signal control, road geometry and others)
			• Increase road capacities and vehicle capacities
			• Reduce empty passenger and freight trips (provide demand-responsive transport and integrate activities)
	Strategy to improve integration between traffic-related activities		• Improve integration of activities involving multiple transport
			• Improve intermodality of transport modes (PT to FT)
	Strategy to reduce the disturbances of traffic flow		• Reduce idling of traffic on roads (improve traffic flow)
			• Reduce idling of traffic at interesections (signal control)
	Strategy to avoid or reduce unnecessary car-based mobility	Traffic Demand Reduction	• Provide alternatives to IMT (trip reduction ordinances)
			• Charge disaster tourist operations in disaster areas
	Strategy to increase the vehicle utilisation of transport modes		• Increase vehicle capacities of public transport (high capacity buses)
			• Promote high occupancy modes (carpooling and ride sharing)
	Strategy to shift the use of individual motorised transport		• Improve alternatives of IMT (improve PT accessibility and service)
			• Shift IMT to NMT by ensuring safer NMT modes and routes
To maximise the economic efficiency of existing transport systems	Strategy to improve the transport supply capacity	Transport Supply Augmentation	• Increase road capacities and vehicle capacities
			• Improve transport operation capacities
	Strategy to improve integration between traffic-related activities		• Improve integration of activities involving multiple transport
			• Improve intermodality of transport modes
	Strategy to reduce the disturbances of traffic flow		• Improve the traffic flow conditions (reduce congestion,travel time)
			• Improve traffic incident management
	Strategy to increase the vehicle utilisation of transport modes	Traffic Demand Reduction	• Increase vehicle capacities of public transport
			• Promote high occupancy modes (carpooling and ride sharing)
	Strategy to shift the use of individual motorised transport		• Shift IMT to PT by providing high occupancy PT modes
			• Shift IMT to NMT by ensuring proper routes

Table 6-3: Traffic management strategies for economy objectives

Transport environment objectives of traffic management

It is observed that the ambient environmental quality of disaster-affected area is drastically reduced. The urban transport system includes both the passenger transport and commercial transport. Based on the US Department of Energy estimates, of the total energy used by the transport sector, approximately 65% is consumed by gasoline-powered vehicles, primarily individual motorised transport. The commercial transport consists of mostly diesel-powered vehicles (trains, merchant ships, heavy trucks, etc.) which consumes about 20%, and air transport consumes most of the remaining 15 % (US Dept. of Energy, "Annual Energy Outlook" (February 2006)). The environmental impacts of traffic on disasters are often ignored or are least-considered in traffic management in cases of disasters. One reason is the relatively higher importance given by transport departments to the other disaster traffic management goals. Often there are trade-offs between the goals related to transport accessibility and transport safety versus transport economy and transport environment. This section describes the formulated environmental objectives of disaster traffic management which are (see Table 6-4):

Objective 1: Minimise the consumption of energy resources in transport

This objective of minimising consumption of energy resources is aimed to reduce consumption of fossil fuel (mainly gasoline) for traffic operations during disasters. The fulfilment of this objective will not only serve the environmental goal but also the economy goal of disaster traffic management. The objective is measurable in many ways as per capita consumption of energy, energy consumption per person-kilometre, energy consumption per vehicle kilometre.

Objective 2: Reduce the air pollution related to transport

It is observed that traffic generating activities of disaster management produce negative impacts on the environment by increasing the air pollution levels. This objective of minimising the air pollution

is aimed at reducing the air pollution due to traffic and transport operations. The objective proposes measures which reduce the total amount and rates of traffic related emissions of all polluting transport modes. The air pollution due to traffic operation can be decreased by improving traffic flow conditions in cases of bad weather, accidents, incidents, etc. The air pollution due to transport modes can be decreased by improving vehicle conditions and strict prohibition on the operation of such transport modes. This objective is measureable in concentration of pollutants at different times, volume of pollutant (e.g. CO_2 emissions) released per person-kilometre, ton kilometre, vehicle kilometre, etc.

Objective 3: Reduce the noise pollution related to transport

This objective of reducing the noise pollution is aimed at reducing the noise levels and thus supporting the quality of life in disaster-affected areas. This objective is measurable by noise levels in **db (A**) at different locations where noise is produced.

Transport Environment Objectives	Possible Traffic Management Strategies	Type of Strategy	Approaches
To minimise the consumption of energy resources in transport	Strategy to improve the transport supply capacity	Transport Supply Augmentation	• Improve traffic flow conditions (traffic signal control, road geometry and others)
			• Increase road capacities and vehicle capacities
			• Reduce empty passenger and freight trips (operate demand-responsive transport)
	Strategy to improve integration between traffic-related activities		• Improve integration of activities involving multiple transport
			• Improve intermodality of transport modes
	Strategy to reduce the disturbances of traffic flow		• Reduce idling of traffic on roads (improve traffic flow)
			• Reduce idling of traffic at interesections (signal control)
	Strategy to avoid or reduce unnecessary car-based mobility	Traffic Demand Reduction	• Provide alternatives to trip making (telecommuting-work at home)
			• Provide alternatives to trip makings (telesubstitutions-shopping)
	Strategy to increase the vehicle utilisation of transport modes		• Increase vehicle capacities of public transport
			• Promote high occupancy modes (carpooling and ride sharing)
	Strategy to shift the use of individual motorised transport		• Improve alternatives of IMT (PT accessibility and service)
			• Improve alternatives of IMT (cycling and walking)
To reduce the air pollution related to transport	Strategy to improve the transport supply capacity	Transport Supply Augmentation	• Improve vehicle conditions (vehicle checkups)
			• Improve road conditions (improved road geometry)
	Strategy to reduce the disturbances of traffic flow		• Improve the traffic flow conditions (reduce congestion)
			• Improve the traffic flow conditions (impose speed limits)
	Strategy to increase the vehicle utilisation of transport modes	Traffic Demand Reduction	• Increase vehicle capacities of public transport
			• Promote high occupancy modes (carpooling and ride sharing)
	Strategy to shift the use of individual motorised transport		• Shift IMT to PT by providing high occupancy PT modes
			• Shift IMT to NMT by ensuring proper routes
To reduce the noise pollution related to transport	Strategy to improve the transport supply capacity	Transport Supply Augmentation	• Improve vehicle conditions (vehicle checkups)
			• Improve road conditions (improved road geometry)
	Strategy to reduce the disturbances of traffic flow		• Improve traffic flow conditions (signal control)
			• Enforce speed limits (establish speed zones)
	Strategy to improve the spatial distribution of traffic volume	Traffic Demand Reduction	• Provide seperate routes to freight and other noise-producing transport
	Strategies to improve the temporal distribution of traffic volume		• Ensure time segregation of freight and other noise-producing noise-producing traffic (FT)

Table 6-4: Traffic management strategies for environmental objectives

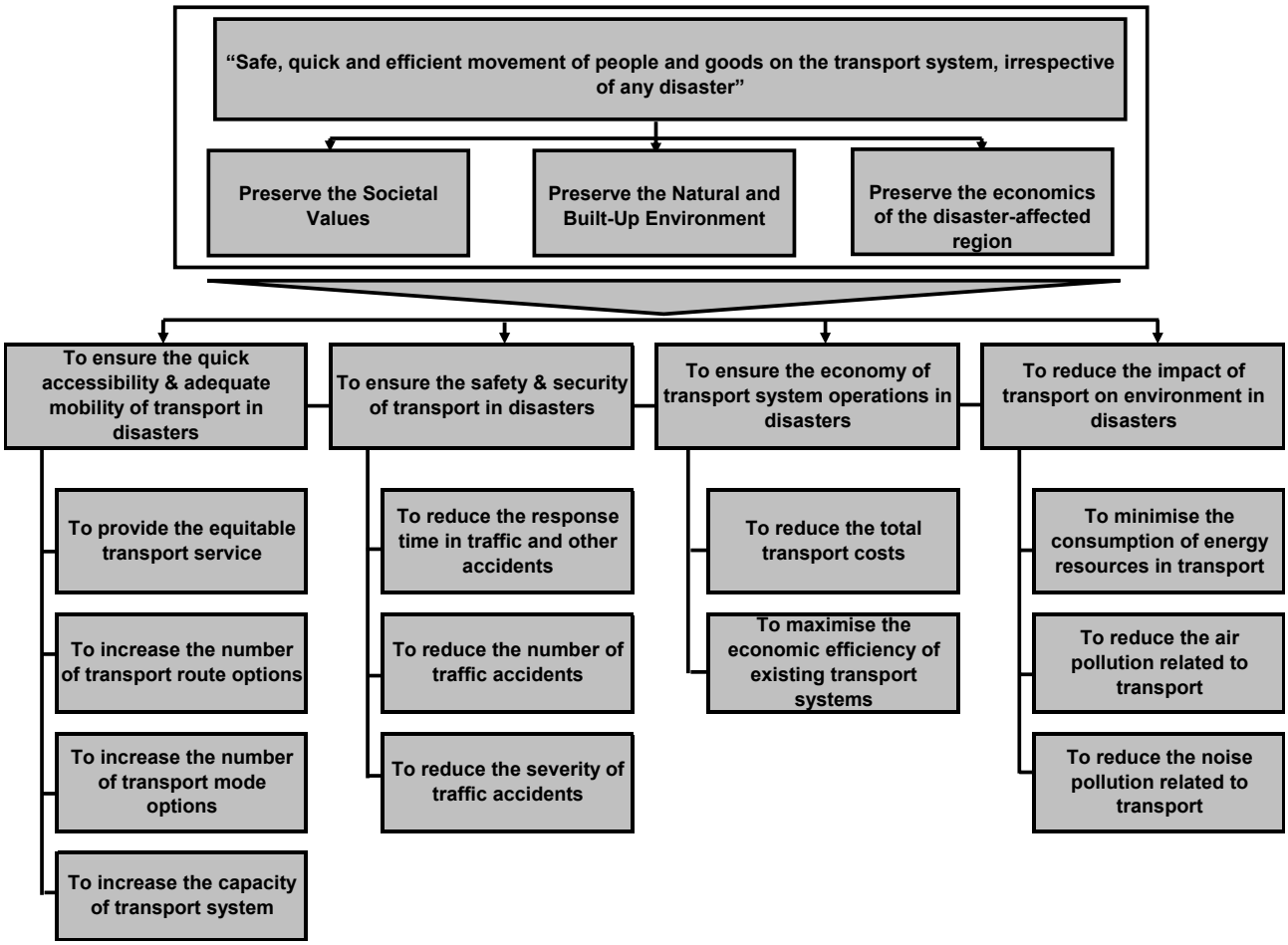


Figure 6-1: Traffic management operational framework in disasters

6.6 Summary

This chapter provided the traffic management concept of operations in disasters by identifying the clear vision and mission statements. The framework of TM operations also identified the goals of traffic management and provided objectives under four TM goals of accessibility and mobility, safety and security, economy and environment. This chapter also provided the overview of probable approaches of traffic management in achieving the TM objectives. The approaches are differentiated based on transport supply augmentation strategies and traffic demand reduction strategies. Also various possible strategies under the broad influence areas of strategies (transport supply and traffic demand) are identified for each objective of traffic management. The operation framework of traffic management also provided the use of TM goals and objectives as assessment tools to assess the traffic management measures based on their effectiveness in fulfilling TM goals and objectives (explained in next chapters).

7 Disaster Traffic Management Measures and their Qualitative Assessment

7.1 Introduction

This chapter consists of two broad sections, one section deals with the description of traffic management measures in cases of disasters, and the other section deals with the qualitative assessment of the selected measures.

The section on description of measures provides the aim of the measure, intended impacts of the measure and, the infrastructure and operation requirements of the measure. In some cases, it also describes the mechanisms involved in the implementation of the traffic management measure. Finally, the description also provides the list of complimentary measures necessary for the application of the candidate measure.

In the next section on qualitative assessment, two broad qualitative assessments are performed and explained in this chapter. The first qualitative assessment is aimed at obtaining the relative weights of importance provided by the experts regarding the importance given to traffic management goals and descendent objectives limited only in cases of disasters.

The second qualitative assessment is a self-conducted assessment of individual TM measures based on two assessment modules. First assessment module deals with the effectiveness of measures and the second assessment module deals with the difficulty of implementation of measures. Traffic management factors of assessment were identified for both the assessment modules (Table 7-5). The criteria of traffic management factors for both the assessments were also identified. Although the assessment performed on TM measures is entirely based on the qualitative data yet the possible quantitative indicators were identified which could indicate the fulfilment of the criteria of traffic management factors when available.

Finally the qualitative assessment model is developed which uses results of both the assessments and provides effectiveness and difficulty scores. These scores are used to form six priority classes of traffic management measures based on high, medium or low levels of effectiveness and applicability. The inferences derived from the assessment results of TM measures are also discussed.

7.2 Traffic Management Measures

Pre-selection of measures

A total of twenty-seven traffic management measures are selected which bear the potential for effective application in the management of disasters. Only those traffic management measures that conform to the disaster response and disaster recovery are selected for evaluation. The twenty-seven TM measures include eight public transport measures, two non-motorised transport measures, four individual motorised transport measure, ten multi-modal and inter-modal transport measures and a total of three freight transport measures (See Annexure B). During the selection of TM measures, literature was reviewed and only those measures with documented effectiveness in disaster situations were selected. Although the selected measures are proven effective in many disasters yet the measures will also be later evaluated for their effectiveness and applicability in the disaster situation. Subsequently, the measures are ranked based on their effectiveness and applicability for disaster situations. The TM measures also consider five categories of requirements for the TM measures implementation. These categories of requirements are: (i) **infrastructure requirements**, (ii)

administrative and organisational requirements, (iii) **economic requirements**, (iv) **technical and operational requirements**, and (v) **information requirements** (Table 7-1). The requirements of measures indicate the resources needs and the mechanisms required for the implementation. In practice, the implementation of an individual measure demand several requirements (given measures requirements) but assigning an individual measure based on the category of requirements would emphasise the primary requirement for the purpose of implementation of the measure.

Measures description

This Annexure B describes the TM measures based on the aim of the measure, the intended impacts of the measures, mechanisms involved in the measure implementation and the required devices for the measure implementation. The measures are categorised and explained based on category of transport modes for example public transport, non-motorised transport, individual motorised transport, multi-modal and inter-modal transport and freight transport.

S.No.	Traffic Management Measures	Administrative measures	Economical measurs	Technical and Operational measures	Informational meaures	Infrastructural measures
PT	Public Transport Measures					
1	Public Transport Network Improvement			X		X
2	Public Transport Scheduling Improvement			X	X	
3	Public Transport Accessibility Improvement	X		X		
4	Public Transport Capacity Improvement			X		X
5	Special Disaster Transport Services		X	X		
6	Public Transport Right-of-Way Prioritisation	X		X		
7	Public Transport Information Services			X	X	
8	Public Transport Management Centre	X		X	X	
NMT	Non-Motorised Transport Measures					
1	Establishment of Pedestrian routes & Facilities			X		X
2	Establishment of Bicycle routes & Facilities			X		X
IMT	Individual Motorised Vehicle Measures					
1	Carpooling & other Ride Sharing Programs	X	X			
2	Car Rental Services	X	X			
3	Automobile Roadway Repair Service		X			X
4	Special Traffic Rules Enforcement	X		X		
MIM	Multimodal and Intermodal Transport Measures					
1	Economic or Preferential Incentives	X	X			
2	Trip reduction & Land-use Modification Ordinances	X		X	X	
3	Road Network Control			X		X
4	Road Section Control			X		X
5	Improvement of Signalised Traffic Control			X		X
6	Improvement of Non-signalised Traffic Control			X		X
7	Improvement of Inter-modal and Parking Facilities			X		X
8	Traffic & Disaster Information Service			X	X	
9	Disaster Traffic Management Centre			X	X	
10	Work- Zone Coordination & Management Centre			X	X	
FR	Freight Transport Measures					
1	City Logistics System	X		X		
2	Household Goods Delivery Transport System	X			X	
3	Freight Traffic Operations Control			X		

Table 7-1: TM measures classification by required transport resources and modes

7.3 Qualitative Assessment of Traffic Management Measures

Methodology

The qualitative assessment of TM measures involves two estimations; the first estimation of relative weights of importance of TM assessment factors and their corresponding criteria. These relative weights are obtained from the traffic experts by conducting an expert-opinion interview. The formulated TM goals are referred as traffic management effectiveness-assessment factors and similarly TM objectives are referred as criteria of effectiveness assessment of TM measures.

Four effectiveness assessment factors that are used for the effectiveness assessment of measures are:

- **transport accessibility and mobility**,
- **transport safety and security**,
- **transport economy**, and
- **transport environment**.

The criteria of effectiveness assessment under each effectiveness assessment factor are given in Table 7-3.

Four difficulty assessment factors that are used for the difficulty assessment of measures are:

- **transport costs (affordability)**,
- **technical systems**,
- **institutional participation**, and
- **public acceptance**.

Similarly the criteria of difficulty assessment factors under each difficulty assessment factor are given in Table 7-4Table 7-5. A questionnaire containing twenty-seven questions in three parts is designed. The first part provides the personal information of the traffic expert. The second part of the questionnaire is aimed at obtaining both the subjective opinions on the importance of TM factors (previously formulated TM goals) and their corresponding descendent criteria of assessment (objectives of TM goals) in cases of disasters. Similarly, the third part of the questionnaire is aimed at obtaining the subjective opinions on difficulty of implementation of measures based on four TM difficulty factors given above. Relative weights are also obtained for the criteria of difficulty assessment. A sample of the questionnaire is given in the Annexure C.

A group of fifteen traffic experts are chosen to provide response regarding their opinions on the importance of TM factors (effectiveness and difficulty factors) and their descendent criteria in the designed questionnaire. The obtained opinions are then analysed using an AHP technique for the calculation of final relative weights of importance in percentages (see Table 7-3 and Table 7-4). The obtained relative weights of importance are then fixed for the further analyses.

The second estimation involved a self-conducted assessment of 27 pre-selected TM measures. This estimation involves ratings based on the fulfilment of criteria of assessment for both effectiveness and difficulty. Four rating scales from 0 to 3 are used to denote the effectiveness and difficulty of measures based on the given description of a measure (Table 7-6 to Table 7-9 and Table 7-11 to Table 7-14).

Finally, effectiveness and applicability scores are calculated by using the formulae given in the next sections (Formula 7-1 and Formula 7-2). The effectiveness and difficulty scores are the basis of the

formation of priority classes of TM measures. In the following sections both the estimations are explained.

First Estimation: Estimation of relative weights of importance

The calculated weights of importance indicate the importance of the TM factors and emphasises their contribution in the success of disaster traffic management.

The relative weights of importance are calculated in percentages using a mathematical technique called **Analytic Hierarchy Process** (abbreviated as AHP). The AHP is a widely used technique for multi-criteria decision analysis (Saaty, 1959). This technique enables people to make decisions which involve multiple concerns of planning, setting priorities, selecting the best among a number of alternatives and allocating resources. The AHP technique has been employed in this study to obtain weights of importance based on the intuitive judgements of traffic experts. This technique involves a pair-wise comparison of different alternatives, which are TM factors and criteria of assessment in this study. Although AHP technique can use three approaches for specifying pair-wise comparison which are: numerical, graphical and verbal mediated; the numerical technique is employed due to the limitations of the study. For a numerical approach the participant of the interview (in this study a traffic expert) answered each question with a number, for example, “attribute x (TM factor x) is 3 times more desirable than attribute y (TM factor y)”. Four-point numerical scales are used with 0.5 scale interval between the scales elements to present variations (see Table 7-2). The detailed description of the steps involved in the analytic hierarchy process is given in the Annexure D.

Verbal Expression	Numerical Scale
Equal Importance/Equal desirability of alternatives	**1**
Moderate importance of one attribute over another/Moderate desirability of one alternative over another	**1.5**
Significant importance of one attribute over another/Strong desirability of one alternative over another	**2**
Extreme importance of one attribute over another/Very strong desirability of one alternative over another	**2.5**

Table 7-2: Numerical scale for pair-wise comparison

The pair-wise comparison of traffic management factors of assessment is examined individually to determine the relative weights of importance in percentage for each traffic expert. The final weights of importance of each TM factor and corresponding criteria of assessment are estimated by calculating the geometric mean of the percentages of individual weights of importance of all selected traffic experts. The geometric mean is useful in finding the average of percentages, ratios, indexes, or growth rates. The geometric mean is defined as the nth root of the product of n values (Bluman, 2005).

The AHP technique is used only for estimating the relative weights of importance of goals (factors) and objectives (criteria) used for the assessment. In the next estimation the TM measures are not compared, however the effectiveness as well as the difficulty of a measure is based on the description of level-of-effectiveness and level-of difficulty.

Q.8 To achieve the goal of adequate safety and security of transport in Disasters, how would you rank the traffic management objectives given below?

Hint : Rank them as 1, 2, 3, with rank (1) given to most important to rank (3) given to the least important

Note : Same rank can also be given to different objectives

Traffic management safety and security objectives in Disasters(S/S)	Rank
To reduce the response time for traffic and other accidents **(RESPONSE)**	
To reduce the number of traffic accidents **(FREQ)**	
To reduce the severity of traffic accidents **(SEV)**	

Q.9 Please fill the table below by comparing the goal against the goal as per rules indicated. Please use the rank (given by you in above question 8) in the ascending order.

Hint : Use the abrv. RESPONSE, FREQ, SEV and sort them in descending order in the table below

Rule : give "0" if the two goals in question are equally important

give "X" if the basic goal is slightly more important than the other goal (in horizontal)

give "XX", if the basic goal is significantly more important than the other goal (in horizontal)

give "XXX" if the basic goal is extremely more important than the other goal (in horizontal)

Note : The above given objectives are not ranked in any order

			Objectives		
		Objective abrv.	1	2	3
Basic objectives	Rank				
	Rank 1		1		
	Rank 2			1	
	Rank 3				1

Figure 7-1: A sample of expert opinion survey

The result of the analysis of relative weights of importance (effectiveness factors) indicates the following:

- **the transport accessibility and mobility factor is rated as the most important factor which has a relative weight of 38%**,
- **the transport safety and security factor is rated as the second important factor which has a relative weight of 30%**,
- **the transport economy factor is rated as the third important factor which a relative weight of 19%**, and
- **the transport environment factors is rated as the fourth important factor which has a relative weight of 13% respectively**.

Similarly, the result of the analysis of relative weights of importance (difficulty factors) indicates the following:

- **the requirement of transport costs involved in TM measure implementation is rated as the most difficult factor with a relative weight of 31%**,
- **the requirement of technical systems in the TM measure implementation is ranked second in difficulty with a relative weight of 27%**,
- **the requirement of institutional participation in the TM implementation is ranked third in difficulty with a relative weight of 24%**, and
- **the requirement of public acceptance is ranked fourth and least in difficulty with a relative weight of 18% respectively**.

The relative weights of importance of TM factors and criteria based on TM effectiveness and difficulty assessment factors are given in the Table 7-3. The resultant weights of criteria are the relative percentages of importance obtained when all TM factors are considered.

TM effectivenss assessment factors	Factor weights	Criteria of assessement (TM objectives)	Criteria weights	Resultant weights of criteria
Transport Accessibility and Mobility	38%	Promotion of equity of transport	28%	10.6%
		Increase of number of routes	23%	8.7%
		Increase of number of modes	22%	8.4%
		Increase of transport capacity	27%	10.3%
Transport Safety and Security	30%	Reduction of response time of traffic and other accidents	33%	9.9%
		Reduction of number of traffic and other accidents	38%	11.4%
		Reduction of severity of traffic and other accidents	29%	8.7%
Transport Economy	19%	Reduction of total transport costs	49%	9.3%
		Maximisation of transport efficiency	51%	9.7%
Transport Environment	13%	Minimisation of consumption of energy resources	38%	4.9%
		Reduction of air pollution	36%	4.7%
		Reduction of noise pollution	26%	3.4%

Table 7-3: Relative weights of TM effectiveness factors and criteria of assessment

TM difficulty assessment factors	Factor weights	Criteria of assessement	Criteria weights	Resultant weights of criteria
Required transport costs	31%	Total investment costs involved for measure implementation	57%	17.7%
		Total operation costs involved for measure implementation	43%	13.3%
Required technical systems	27%	Total operation & control Systems involved for measure implemenation	60%	16.2%
		Total information systems involved for measure implementation	40%	10.8%
Required institutional participation	24%	Involvement of transport related institutions for measure implemenation	41%	9.8%
		Involvement of political bodies for measure implemenation	59%	14.2%
Required public acceptance	18%	Acceptance of transport users for measure implemenation	47%	8.5%
		Acceptance of non-transport users for measure implemenation	53%	9.5%

Table 7-4: Relative weights of TM difficulty factors and criteria of assessment

Second Estimation: Rating the traffic management measures

In this section, rating scales of the traffic management measures based on fulfilment of criteria of assessment are presented. The qualitative rating scales are referred to as **levels-of-effectiveness (LOE)** and **levels-of-difficulty (LOD)**. In addition, descriptions of TM measures are created and these descriptions are used as guide to assign the rating scales to different TM measures. Based on the known or intended impacts of a TM measure on the criteria (effectiveness) and the limitations of measure (difficulties) in terms of resources requirement for implementation, the LOE and LOD scales are assigned respectively.

TM measures assessment modules	TM factors of assessment	Criteria of assessment	Possible indicators of assessment
Effectiveness-of-measures assessment	Transport Accessibility and Mobility	Promotion of equity of transport	Fare structure, tax subsidies, travel oppurtunities per capita, per-person-km.
		Increase of number of routes	% of routes per destination, travel time, travel distance and per transport mode.
		Increase of number of modes	Number of mode options per trip for various trip purposes.
		Increase of transport capacity	Road length, number of PT stops, terminals, parking capacity, service frequeny of different transport, etc.
	Transport Safety and Security	Reduction of response time of traffic and other accidents	Response time per accident type, response time distribution, etc.
		Reduction of number of traffic and other accidents	Accidents per vehicle population, accident density (accident per km of road length), etc.
		Reduction of severity of traffic and other accidents	Number of deaths per vehicle population, fatalities rate per year, total costs of property damages per accident, etc.
	Transport Economy	Reduction of total transport costs	Total costs per person-kilometres, total costs per ton-kilometres, total costs per activity, etc.
		Maximisation of transport efficiency	Time per unit passenger-km, per ton-km, per activity, etc.
	Transport Environment	Minimisation of consumption of energy resources	Per capita consumption of energy, energy consumption per person-km, ton-km, vehicle-kilometre, etc.
		Reduction of air pollution	Volume of pollutant released per person-kilometre, ton kilometre, vehicle kilometre, etc.
		Reduction of noise pollution	Noise levels in db(A) at different locations.
Difficulty-of-measures assessment	Transport Costs	Investment costs involved	Total investment (infrastructure and subsidies) costs, ownership costs per km., etc.
		Operation and maintenance costs involved	Vehicle operating costs(Gas and oil, maintenance, tyres etc.) per km., staff costs per km., etc.
	Technical Systems	Use of operation and control systems	% of use of manual/automatic/intelligent traffic control and operation systems, etc.
		Use of information systems	Requirements of information dissemination, % of use of dynamic and static information systems, etc.
	Institutional Participation	Involvement of political bodies	Number of joint ventures, people, offices involved for measure implementation, % political and administrative opposition, Need of institutional reforms, scale of involvement(State level), etc.
		Involvement of transport related institutions	Number of agreements for measure implementation, scale of involvement, etc.
	Public Acceptance	Acceptance of transport users	% of acceptance of transport users for TM measures, number or % of informed people, etc.
		Acceptance of non-transport users	% of acceptance of non-transport users for TM measures, number or % of informed people, etc.

Table 7-5: Traffic management assessment modules, factors, criteria and possible indicators

The adopted qualitative rating scales ranges from 0 to 3, in the increasing order of level of effectiveness or difficulties in fulfilment of various criteria of assessment. Thus, a measure which has a highest level of effectiveness to meet a given criteria of assessment is rated as 3 and similarly a measure which has a highest level of implementation difficulties (low applicability) based on the criteria of assessment is rated as 3.

All twenty-seven measures are assessed for twelve criteria of assessment related to effectiveness of measures in fulfilling the TM factors of assessment. Similarly eight criteria of assessment related to

difficulty of measures (indicates applicability) are included in the measure assessment. The twelve criteria were based on TM factors of transport accessibility and mobility (four criteria), transport safety and security (three criteria), transport economy (two criteria) and transport environment (three criteria). Similarly another eight criteria of difficulty assessment of measures are based on the transport costs (two criteria), technical systems (two criteria), institutional participation (two criteria) and public acceptance (two criteria). Table 7-5 provides the complete TM assessment modules, factors of assessment, criteria of assessment and possible indicators of assessment of traffic management measures.

The following section describes the criteria of assessment under each traffic management factor.

- **Transport accessibility and mobility criteria**

Each measure is evaluated based on its effectiveness in providing equity, increasing the number of transport route options, increasing the number of transport mode options and increasing the overall capacity of the transport system. However the level-of-effectiveness of a measure will depend on the adoption of approaches given in Table 6-1 . The Table 7-6 provides the level-of-effectiveness scales based on description of TM measures.

Transport Accessibility & Mobility Criteria	Description of Levels-of-effectiveness of measure	LOE (Scale)
To provide equitable transport service to the disaster-affected people	This measure will highly increase the equity in the use of transport facilities and transport services to all mobility disabled groups.	**3**
	This measure will moderately increase the equity in the use of transport facilities and transport services to some mobility disabled groups.	**2**
	This measure will slightly increase the equity in the use of transport facilities and transport services to a very few mobility disabled groups.	**1**
	This measure will have no impact on the criteria of assessment.	**0**
To increase the number of transport route options	This measure will be highly effective in increasing the number of routes for most transport modes and user groups.	**3**
	This measure will be moderately effective in increasing number of routes for some transport modes and user groups.	**2**
	This measure will be slightly effective in increasing number of routes for a very few transport modes and user groups.	**1**
	This measure will have no impact on the criteria of assessment.	**0**
To increase the number of transport mode options	This measure will significantly increase the mode options of many user groups.	**3**
	This measure will moderately increase the mode options for some user groups.	**2**
	This measure will slightly increase the mode options for a very few user groups.	**1**
	This measure will have no impact on the criteria of assessment.	**0**
To increase the capacity of the transport system	This measure will significantly increase the infrastructure and operation capacities of one or more transport modes and services.	**3**
	This measure will moderately increase the infrastructure and operation capacities of one or more transport modes and services.	**2**
	This measure will slightly increase the infrastructure and operation capacities of one or more transport modes and services.	**1**
	This measure will have no impact on the criteria of assessment.	**0**

Table 7-6: Description of LOE scale (Transport Accessibility and Mobility)

- **Transport safety and security criteria**

Each measure is evaluated based on its effectiveness in reducing the response time of accidents, reducing the frequency of accidents and reducing the fatality of traffic accidents in cases of disasters. However the level-of-effectiveness of a measure will depend on the adoption of approaches given in Table 6-2. The Table 7-7 provides the level-of-effectiveness scales based on description of TM measures.

Transport Safety and Security Criteria	Description of Levels-of-effectiveness of measure	LOE (Scale)
To reduce the response time in traffic and other accidents	This measure is dedicated to significantly reduce the response time in most traffic and other accidents by improving the road and traffic flow conditions.	3
	This measure will indirectly reduce the response time in most traffic and other accidents by either moderately improving road conditions or traffic flow conditions.	2
	This measure will indirectly reduce the response time in most traffic and other accidents by either slightly improving road conditions or traffic flow conditions.	1
	This measure will have no impact on the criteria of assessment.	0
To reduce the number of traffic accidents	This measure will reduce accidents by imparting vehicle segregation /road safety regulations/shifting trips principles to reduce potential conflicts involving major transport modes.	3
	This measure will reduce accidents by imparting vehicle segregation /road safety regulations/shifting trips principles to reduce potential conflicts involving some transport modes.	2
	This measure will reduce accidents by imparting vehicle segregation /road safety regulations/shifting trips principles to reduce potential conflicts involving a few transport modes.	1
	This measure will have no impact on the criteria of assessment.	0
To reduce the severity of traffic accidents	This measure will significantly reduce the fatal accidents directly by minimising the potential conflicts of heavy vehicles (FT) with other PT, IMT and NMT vehicles.	3
	This measure will moderately reduce the fatal accidents indirectly by minimising the potential conflicts of PT and IMT vehicles with other IMT and NMT vehicles.	2
	This measure will slightly reduce the fatal accidents indirectly by minimising the potential conflicts of IMT and NMT vehicles with other IMT and NMT vehicles.	1
	This measure will have no impact on the criteria of assessment.	0

Table 7-7: Description of LOE scale (Transport Safety and Security)

- **Transport economy criteria**

Each measure is evaluated based on its effectiveness in reducing the total transport costs and maximising the economic efficiency of existing transport systems. The reduction of total transport costs involves the approach of reducing the total trips and maximising of the economic efficiency involves only optimisation of existing transport services without trip reduction approach. The level of fulfilment of criteria depends on level-of-effectiveness of various approaches stated in Table 6-3. The level of effectiveness scales based on description of TM measures for economy criteria are given in Table 7-8.

- **Transport environment criteria**

Each measure is evaluated based on its effectiveness in reducing the consumption of energy resources, reducing the air pollution and the noise pollution related to transport. The reduction of consumption of energy in transport is mainly associated with the consumption of fossil-fuels. The

reduction of air pollution is mainly related to the air emissions due to fossil-fuel transport. The reduction of noise pollution is related to operation of both fossil-fuel based and non-fossil fuel based transport modes. The level of fulfilment of criteria depends on level-of-effectiveness of various approaches stated in Table 6-4. The level of effectiveness scales based on description of TM measures for environment criteria are given in Table 7-9.

Transport Economy Criteria	Description of Levels-of-effectiveness of measure	LOE (Scale)
To reduce the total transport costs	This measure will reduce the total transport costs by directly reducing the total travel demand.	**3**
	This measure will indirectly reduce the total transport costs by shifting of trips using uneconomical single occupancy vehicles to economical high occupancy vehicles.	**2**
	This measure will indirectly reduce the total transport costs by shifting of trips to NMT modes and/or improving the traffic flow conditions.	**1**
	This measure will have no impact on the criteria of assessment.	**0**
To maximise the economic efficiency of existing transport systems	This measure will significantly maximise transport capacity, time, distance and costs by ensuring better mode connections, high capacity modes and high speed corridors.	**3**
	This measure will moderately maximise transport capacity, time, distance and/or costs by ensuring mode connections, high capacity modes and high speed corridors.	**2**
	This measure will slightly maximise transport capacity, time, distance and/or costs by ensuring mode connections, high capacity modes and high speed corridors.	**1**
	This measure will have no impact on the criteria of assessment.	**0**

Table 7-8: Description of LOE scale (Transport Economy)

Transport Environment Criteria	Description of Levels-of-effectiveness of measure	LOE (Scale)
To minimise the consumption of energy resources in transport	This measure will significantly reduce the use of petroleum based fuel by reducing the trips and/or shifting trips to energy efficient transport modes.	**3**
	This measure will moderately reduce the use of petroleum based fuel by promoting the high occupancies in all transport modes using gasoline.	**2**
	This measure will slightly reduce the use of petroleum based fuel by implementing effective traffic control techniques for improving traffic flow conditions.	**1**
	This measure will have no impact on the criteria of assessment.	**0**
To reduce the air pollution related to transport	This measure will significantly reduce air pollution by directly implementing effective traffic control techniques and/or shifting trip to less or no polluted transport modes (PT and NMT).	**3**
	This measure will moderately reduce the air pollution by promoting the use of high occupancy vehicles.	**2**
	This measure will slightly reduce the air pollution concentration by shifting and distributing traffic in different time and space (in off-peak hours & spaces) and/or improving traffic flow conditions.	**1**
	This measure will have no impact on the criteria of assessment.	**0**
To reduce the noise pollution related to transport	This measure will significantly reduce noise pollution by implementing strict traffic control techniques and/or shifting trip to high capacity and less noisy transport modes (PT and NMT).	**3**
	This measure will moderately reduce the noise pollution by promoting the use of high occupancy vehicles.	**2**
	This measure will slightly reduce the noise pollution levels by shifting and distributing traffic in different time and space (in off-peak hours & spaces) and/or improving traffic flow conditions.	**1**
	This measure will have no impact on the criteria of assessment.	**0**

Table 7-9: Description of LOE scale (Transport Environment)

While rating measures on LOE scales, besides the main consideration of criteria fulfilment of a TM measure, several other considerations are made. These considerations are:

- possible impact of a measure on transport demand or on supply,
- types of approaches followed for the criteria fulfilment,
- scale of the application of TM measure,
- direct promotion of use of transport facilities or services, etc.

In Table 7-10, characteristics of TM measures and their correspondingly assigned LOE scales are summarised for LOE scales 1, 2 and 3.

LOE Scale 1	LOE Scale 2	LOE Scale 3
Low impact of measure	Moderate impact of measure	High impact of measure
Indirect fulfilment of criteria	Indirect fulfilment of criteria	Direct fulfilment of criteria
Low Scale of application	Moderate scale of application	Large scale of application
Complimentary measures	Complimentary measures	Basic measures
Indirect promotion of use of transport facilities or services	Indirect promotion of use of transport facilities or services	Direct promotion of use of transport facilities or services
Results in minor shifting to traffic to public transport	Results in moderate shifting to traffic to public transport	Results in major shifting to traffic to public transport
High costs	Moderate costs	Low costs
Involve high fuel consumption	Involve high fuel consumption	Involve less fuel consumption
Promotes low safety	Promotes moderate safety	Promotes most safety
Improves traffic flow due to indirect reduction of traffic	Improves traffic flow due to indirect reduction of traffic	Improves traffic flow due to direct reduction of traffic

Table 7-10: Summary of LOE scale

Similar to the level-of-effectiveness scales, level-of-difficulty scales (LOD) are developed. The LOD scales are assigned to eight difficulty criteria, which indicated the corresponding difficulties of implementation of TM measures.

- **Transport costs difficulty criteria**

The cost of the implementation of TM measures is one of many factors to estimate the applicability of a measure. Many measures that even satisfy most effectiveness and other applicability criteria may not be selected due to the high costs involved in their implementation. The transport costs difficulty criteria include: (i) **the investment costs** and (ii) **the operation and maintenance costs**. The investment costs mainly consist of **cost of equipments**, **planning and design cost**, and **procurement cost of technology** among other costs. The operation and maintenance costs mainly consist of **staff cost**, **cost of traffic control**, **preparation and closing of traffic operation** among other costs. Therefore, if these given costs are high, the selection of a measure for implementation is difficult. The low cost measures are considered favourable measures in the practice of traffic management. The Table 7-11 provides the scaling based on description of level-of-difficulty of a measure related to transport costs.

- **Technical systems difficulty criteria**

In some disasters, the use of advance technical systems is often questionable due to limitations of applications e.g. unavailability of power and communications. The traffic management measures which require the technical systems for traffic operations in both urban and regional areas are often more difficult. The investigation on difficulties suggests the use of multiple forms of traffic systems and technology for disaster traffic operations. One of the main requirements of traffic management in disasters is the use of technical systems that are adaptive to conventional technology that aid the

traffic management even during failures of power and communication. The technical systems difficulty criteria include: (i) **the traffic operation and control systems**, and (ii) **the traffic information systems**. Some of the factors used to assess the difficulty of a measure are: (i) **the compatibility of traffic systems with the conventional systems** (ii) **the scale of modification or implementation of traffic systems**, and (iii) **the type of modification or implementation of traffic systems for the TM measures in disasters**.

Transport Costs Difficulty Criteria	Description of Levels-of-difficulty of measure	LOD (Scale)
Total investment costs involved for measure implementation	This measure will require major investments on construction, procurement of technology and/or subsidies for the measure implementation.	**3**
	This measure will require moderate investment on construction, procurement of technology and/or subsidies for the measure implementation.	**2**
	This measure will require minor investments on procurement of technology and/or subsidies and/or cost of study and planning for the measure implementation.	**1**
	This measure require no investment costs for measure implementation.	**0**
Total operation costs involved for measure implementation	This measures will involve high operation costs due to new organisation, operation staff and maintainence of operation and control equipments.	**3**
	This measures will involve moderate operation costs due to rearrangement of organisation, additional operation staff and necessary maintainence of operation and control equipments.	**2**
	This measures will involve low operation costs due to minor rearrangement of organisation, few additional operation staff and minor maintainence of operation and control equipments.	**1**
	This measure require no operation costs for measure implementation.	**0**

Table 7-11: Description of LOD scale (Transport Costs)

Technical Systems Difficulty Criteria	Description of Levels-of-difficulty of measure	LOD (Scale)
Total Operation & Control Systems involved for measure implemenation	This measures requires a fairly new O&C system for majority of transport modes and/or involves major changes in the existing O&C system for majority of transport modes.	**3**
	This measures requires a moderate changes in the existing O&C system for some specific transport modes.	**2**
	This measures requires some changes in the local O&C system for some specific transport modes.	**1**
	No additional operation or control systems are required	**0**
Total Information Systems involved for measure implementation	This measure requires a dynamic information system for major transport modes and/or involves major changes in the existing information collection, processing and dissemination methods.	**3**
	This measure involves moderate changes in the existing information collection, processing and dissemination methods for some transport modes.	**2**
	This measure involves minor changes in local information equipments for information collection, processing and dissemination for a few transport modes.	**1**
	No additional information systems are required (only conventional traffic signs)	**0**

Table 7-12: Description of LOD scale (Technical Systems)

Table 7-12 provides the scaling based on description of level-of-difficulty of a measure related to use of technical systems.

- **Institutional Participation Difficulty Criteria**

In order to select and implement the measures, institutional participation is a pre-requisite for **effective decision making**, **information sharing and dissemination**, **avoiding duplication and concentration of activities**, **understanding the impacts of disaster on transport system**, and finally **the selection of measures for the implementation**.

Institutional Participation Difficulty Criteria	Description of Levels-of-difficulty of measure	LOD (Scale)
Involvement of Transport related institutions for measure implemenation	This measure demands major involvement of a large number of transport related institutions at national, state and city level.	**3**
	This measure demands moderate involvement of some transport related institutions at state and city level.	**2**
	This measure demands minor involvement of a few transport related institutions at state and city level.	**1**
	No additional involvement of institutions are required	**0**
Involvement of Political bodies for measure implemenation	This measure requires approval from the highest level of governments.	**3**
	This measure requires approval from the State or regional level of governments.	**2**
	This measure requires approval from the City level of governments.	**1**
	This measure requires no additional approval from any governments.	**0**

Table 7-13: Description of LOD scale (Institutional Participation)

However, the involvement of various stakeholders of traffic and disaster management is difficult but often necessary for the measure implementation. The institutional participation difficulty criteria for the measure implementation include both the involvement of transport related institutions and political bodies. Some factors used to assess the difficulty of a measure are: (i) **the level of institutional participation (national, state or city level involvement)**, and (ii) **intensity of institutional participation (major, moderate or low involvement) for the TM measures in disasters**. The investigation on difficulties of implementation of measures suggests: (i) **better relationships with disaster management and traffic management stakeholders**, (ii) **inclusion of traffic management in pro-active and re-active phases of disaster management planning**, and (iii) **a coordinated training with all potential stakeholders of disaster and traffic management**. Thus, the assessment of difficulty is based on difficulty of institutional participation of transport-related and political institutions. The Table 7-13 provides the scaling based on description of level-of-difficulty of a measure related to institutional participation.

- **Public Acceptance Difficulty Criteria**

The success of any TM measure depends largely on the public acceptance. Therefore, TM measures should intend to win the confidence of both the transport users and non-transport users by enhancing the credibility of the administration through coordinated efforts of various public agencies involved in traffic management. The transport user group consists of people using any mode of transport (pedestrians, bicyclists and drivers). Conversely, non-transport user group consists of people who do not use any mode of transport but such groups are indirectly influenced by the use of transport (transport operators, vehicle manufacturer and affected residents). Some of the factors used to assess the difficulty of a measure based on transport users are: (i) **the introduction of new transport processes (production, distribution and consumption processes)**, (ii) **new traffic rules (traffic access restrictions on size, time and locations)**, (iii) **changes in the travel**

behaviour (limited mobility), and (iv) **additional costs borne by the transport users**. Similarly, some factors to assess the difficulty of a measure based on non-transport users are: (i) **the introduction of new transport processes (freight distribution)**, (ii) **use of alternate vehicle technology (high costs of vehicle and a fewer buyers)**, (iii) **degradation of quality of living (noise pollution, air pollution and land use modification)**, and (iv) **additional costs**. The Table 7-14 provides the scaling based on description of level-of-difficulty of a measure related to public acceptance.

Public Acceptance Difficulty Criteria	Description of Levels-of-difficulty of measure	LOD (Scale)
Acceptance of Transport Users for measure implemenation	This measure causes high unacceptance due to any factors related to new transport processes, new traffic rules, changes in travel behaviour and additional costs that impact mobility of major transport user groups.	**3**
	This measure causes moderate unacceptance due to any factors related to new transport processes, new traffic rules, changes in travel behaviour and additional costs that impact mobility of some transport user groups.	**2**
	This measure causes less unacceptance due to any factors related to new transport processes, new traffic rules, changes in travel behaviour and additional costs that impact mobility of a few transport user groups.	**1**
	This measure causes no negative impact that result in inconvenience or unacceptance to transport users.	**0**
Acceptance of Non-transport Users for measure implemenation	This measure causes high unacceptance among non-transport users due to any factors related to degradation of living quality, traffic restrictions, air and noise pollution, land use modification and the additional costs.	**3**
	This measure causes moderate unacceptance among non-transport users due to any factors related to degradation of living quality, traffic restrictions, air and noise pollution, land use modification and the additional costs.	**2**
	This measure causes minor unacceptance among non-transport users due to any factors related to degradation of living quality, traffic restrictions, air and noise pollution, land use modification and the additional costs.	**1**
	This measure causes no negative impact that result in inconvenience or unacceptance to non-transport users.	**0**

Table 7-14: Description of LOD scale (Public Acceptance)

While rating measures on LOD scales, besides the main considerations of criteria fulfilment of a TM measure, several other considerations are made. These considerations are:

- direct or indirect impact on difficulty criteria,
- scale of difficulties,
- level of modifications required,
- involvement of possible stakeholders, etc.

In Table 7-15, characteristics of TM measures and their correspondingly assigned LOD scales are summarised for LOD scales 1, 2 and 3.

An example of rating of TM measures by one expert based on the scheme of LOE and LOD scales is given in the Annexure D. The effectiveness and difficulty scores are deduced from this rating and explained in the next section.

LOD Scale 1	LOD Scale 2	LOD Scale 3
Indirectly influenced by difficulty criteria	Indirectly influenced by difficulty criteria	Indirectly influenced by difficulty criteria
Low scale difficulties	Low scale difficulties	Moderate scale difficulties
Low investment costs	Low investment costs	Moderate investment costs
City-level modification of operation and control systems are required	City-level modification of operation and control systems are required	Local level modification of operation and control systems are required
Involvement of few States and political groups (low-level involvement)	Involvement of few States and political groups (low-level involvement)	Involvement of many States and political groups (moderate-level involvement)
Low modification in the existing organisations	Low modification in the existing organisations	Moderate modification in the existing organisations
Low subsidies are involved	Low subsidies are involved	Moderate subsidies are involved

Table 7-15: Summary of LOD scale

Qualitative Assessment Model

The qualitative assessment model is developed to calculate the final effectiveness and applicability scores of the selected twenty-seven TM measures. The formula used to calculate the effectiveness and difficulty score of a TM measure is given in Formula 7-1 and Formula 7-2.

The formula used to calculate the effectiveness and difficulty score considers the three different values which are: (i) **the relative weight of important of TM factor (Wtmf)**, (ii) **the relative weight of importance of TM criteria of assessment (WC)** and (iii) **the self-conducted assessment rating of the measure (LOE or LOD)**.

$$\mathrm{ES}(ij) = \sum_{m=1}^{4} \mathrm{Wtmf}_m * \left[\sum_{n=1}^{N(m)} \mathrm{WC}_{mn} * \mathrm{LOE}_{mn}^{ij} \right]$$

Formula 7-1: Calculation of effectiveness score of a TM measure

where:

ES_{ij} = Effectiveness score of the TM measure ‘j’, under TM factor ‘i’,

$Wtmf_m$ = Weight of traffic management factor ‘m’ where m=1 to 4

WC_{mn} = Weight of criteria of assessment ‘n’, under traffic management factor ‘m’

LOE_{mn} = Level of effectiveness of measure ‘j’ in category ‘i’ on criteria of assessment ‘n’ under traffic management factor ‘m’

N(m) = Number of n; depending on m

Similarly, the formula used to calculate the difficulty score of a TM measure is given in Formula 7-2.

$$DS(ij) = \sum_{x=1}^{4} Wtmf_x * \left[\sum_{y=1}^{Y(x)} WC_{xy} * LOD_{xy}^{ij} \right]$$

Formula 7-2: Calculation of difficulty score of a TM measure

where:

DS_{ij} = Difficulty score of the TM measure 'j', under TM factor 'i',

$Wtmf_x$ = Weight of traffic management factor 'x' where x=1 to 4

WC_{xy} = Weight of criteria of assessment 'y', under traffic management factor 'x'

LOD_{xy} = Level of difficulty of measure 'j' in category 'i', on criteria of assessment WC, under traffic management factor 'm'

Y(x) = Number of y; depending on x

The calculation of effectiveness and difficulty scores provided the formation of priority classes of TM measures. Six priority classes are formed in the increasing level of difficulties. Table 7-16 gives the detailed ranges for the formation of priority classes of TM measures.

Priority Classes	Effectiveness Score	Difficulty Score
First Priority Class	ES>2,0	(0,5<DS<1,5)
Second Priority Class	ES≤2,0	(0,5<DS<1,5)
Third Priority Class	ES>2,0	(1,5≤DS<2,0)
Fourth Priority Class	ES≤2,0	(1,5≤DS<2,0)
Fifth Priority Class	ES>2,0	(2,0≤DS<2,5)
Sixth Priority Class	ES≤2,0	(2,0≤DS<2,5)

Table 7-16: Formation of priority classes of TM measures

Due to the proven effectiveness of twenty-seven measures in different disaster-prone and disaster-affected countries, only two ranges for effectiveness scores are set based on effectiveness score ranges which are, ES≥2.0 and ES<2.0. Similarly, three ranges are set based on difficulties score ranges which are explained in Table 7-16. The complete assessment of twenty-seven TM measures obtained from effectiveness and difficulty scores of twenty-seven measures and their subsequent allocation in priority classes is given in Table 7-17. The allocation of TM measures in priority classes is an attempt to reveal the applicability of TM measures. The knowledge of TM measures in the priority classes would infer traffic managers and other disaster management stakeholders to investigate the possible solutions to improve the applicability of those measures whose difficulty scores and effectiveness scores are high. The solutions to improve the applicability may be the

inclusion of other complimentary TM measures from the existing TM strategies or completely new measures which might belong to non-transport sectors.

In general, the results of the qualitative assessment indicated that the TM measures which were least effective were also relatively less difficult. Conversely the results also indicated that the most effective TM measures were relatively more difficult to implement.

7.4 Inferences of Assessment Results

Based on the six priority classes the recommended measures are obtained. The first list of recommended measures consists of first and second priority classes. The second list of recommended measures consists of third and fourth priority classes (refer Table 7-17). The fifth and sixth priority classes are not included in the recommended list of measures. Such measures have been referred as residual measures. Assessment of residual measures inferred that despite high effectiveness of TM measures, some measures are difficult to implement in the local environment conditions. This study considers the residual measures for the formulation of TM strategies despite their low applicability in local conditions (disaster-affected or disaster-prone regions). The inclusion of residual measures is required primarily for the success of multiple DTM strategies or the group/s of measures. Therefore corrective actions are proposed to reduce the associated difficulties related to the implementation of such measures. A brief description of the applicability improvement methods of such measures is explained in next section.

The assessment results provided thirteen measures that were selected in the list of first recommended measures. These recommended measures included three pubic transport measures, two non-motorised transport measures, three individual motorised transport measures, three inter-modal and multimodal measures, and two freight transport measures (refer Table 7-17).

Similarly, seven measures were selected in the list of second recommended measures. These recommended measures included four public transport measures; two inter-modal and multimodal measures and one freight transport measure (refer Table 7-17).

A total of seven residual measures are not considered in the list of recommended measures due to their high-difficulty scores (refer Table 7-17).

The following gives the short inferences of the assessment results which are presented categorically based on transport modes.

Public transport measures

All public transport measures except one residual measure (PT-8) qualified for the recommended measures. Such assessment results are due to high level of effectiveness of public transport measures and relatively low level of difficulty. The most recommended PT measures in disasters are: (i) Public Transport Network Improvement, (ii) Public Transport Capacity Improvement, and (iii) Public Transport Information Services. The application of these measures improves the accessibility of public transport, capacity of public transport and pubic transport use through adequate and timely information in disasters. These measures involved moderate to high costs of implementation, low to moderate use of technical systems, less involvement of stakeholders and are widely accepted by the pubic due to more benefits. The second recommended PT measures (PT-2, PT-3, PT-6 and PT-4) are effective measures but are generally cost-intensive measures due to high costs involved in procurement of vehicles, technology and cost of PT operations. The residual PT measure, Public Transport Management Centre is a very effective measure but it failed to qualify due to low applicability as a result of high costs of implementation, potential requirements of information

collection and dissemination equipments and technology and the requirement of participation of stakeholders.

S.No	Traffic Management Measures	Measure Category	Effectiveness				Difficulty				Priority Classes
			Accessibility and Mobility	Safety and Security	Environment	Economy	Cost of implementation	Use of Technical Systems	Stakeholder's participation	Public acceptance	
PT	Public Transport Measures										
1	Public Transport Network Improvement	T-O	●	◕	●	◕	◑	◔	◔	◔	1
2	Public Transport Scheduling Improvement	T-O	●	◕	●	◕	●	◔	○	◔	3
3	Public Transport Accessibility Improvement	T-O/INFR	●	◕	●	◕	●	◔	◔	◔	3
4	Public Transport Capacity Improvement	T-O/INFR	◕	◕	●	●	◕	◔	○	○	1
5	Special Disaster Transport Services	T-O/ADMN	●	◔	○	◔	●	◔	◕	○	4
6	Public Transport Right-of-Way Prioritisation	T-O	◔	●	◕	◑	◕	◑	◑	◔	3
7	Public Transport Information Services	INFO	●	●	◑	◔	◕	◑	◔	○	1
8	Public Transport Management Centre	T-O/INFO	●	●	●	●	◕	●	◕	○	5
NMT	Non-Motorised Transport Measures										
1	Establishment of Pedestrian routes & Facilities	T-O/ADMN	●	◕	●	●	◔	◑	◔	○	1
2	Establishment of Bicycle routes & Facilities	T-O/ADMN	●	◕	●	●	◔	◑	◔	○	1
IMT	Individual Motorised Vehicle Measures										
1	Carpooling & other Ride Sharing Programs	ADMN	◕	○	◕	◕	◔	○	○	◔	2
2	Car Rental Services	ADMN	◕	○	○	○	◔	○	○	◔	2
3	Automobile Roadway Repair Service	ADMN	◔	◕	◔	◔	◔	◑	○	◔	2
4	Special Traffic Rules Enforcement	ADMN	◕	●	◑	◕	◑	◑	◕	●	5
MIM	Multimodal and Intermodal Transport Measures										
1	Economic or Preferential Incentives	T-O/ECO	◑	◔	◑	◕	◑	○	●	○	4
2	Trip reduction & Land-use Modification Ordinances	ADMN	○	◑	●	●	◔	○	●	◑	4
3	Road Network Control	T-O	◑	●	◕	◔	●	●	◑	○	6
4	Road Section Control	T-O	◑	●	◕	◔	●	●	◑	○	6
5	Improvement of Signalised Traffic Control	T-O	◔	◑	◕	◔	◔	◔	○	○	2
6	Improvement of Non-signalised Traffic Control	T-O	◔	●	◕	◔	◑	◔	◔	○	2
7	Improvement of Inter-modal and Parking Facilities	T-O/ADMN	◑	○	◑	◕	◑	◔	◔	○	2
8	Traffic & Disaster Information Service	T-O/INFO	●	●	●	◕	●	●	◑	○	5
9	Disaster Traffic Management Centre	T-O/INFO	●	●	●	◕	●	●	◕	○	5
10	Work- Zone Coordination & Management Centre	T-O/INFO	●	●	●	◕	●	◕	◕	○	5
FR	Freight Transport Measures										
1	City Logistics System	T-O/ADMN	●	◔	●	◕	●	○	●	○	3
2	Household Goods Delivery Transport System	T-O/ADMN	●	◕	●	◕	◔	○	○	○	1
3	Freight Traffic Operations Control	T-O/ADMN	◑	●	◕	◕	◔	◔	◔	◑	1

Note:

First effective group symbols used: ES>2,0	●	◕	
Second effective group symbols used: ES<2,0	◑	◔	○
Most difficult measures, symbols used: DS>2,0	●	◕	
Moderately difficult measures, symbols used: 1,5<DS<2,0	◑	◔	
Least difficult measures, symbol used: DS<1,5	○		

Table 7-17: Final assessment of pre-selected TM measures

Non-motorised transport measures

Both the measures of NMT qualified for first recommended measures (NMT-1 and NMT-2). The use of pedestrian routes and bicycle routes for the short-distance trips during disasters bear a high potential to reduce the total traffic demand. The less costs involved in establishing NMT routes and

facilities compared to other modes, the moderate requirement of technical systems, low requirement of stakeholders participation and high public acceptance are responsible for the inclusion of both measures in the first list of recommended measures.

Individual motorised transport measures

Three measures of IMT qualified for first recommended measures (IMT-1, IMT-2 and IMT-3). All IMT measures addressed the immediate need of improving mobility of IMT users. The qualification of those recommended measures is due to low difficulties of implementation especially limited use of technical systems, limited requirement of stakeholder's participation and very low difficulties related to public acceptance. However the residual measure of IMT (IMT-4) namely 'Special Traffic Rules Enforcement' failed to qualify primarily due to poor acceptance, moderate costs of implementation and the requirement of the use of technical systems. This measure requires large scale involvement of transport and non-transport stakeholders. Additionally, this measure is highly opposed by the public due to increased inconvenience caused to public while the introduction of new rules and regulations.

Multi-modal and inter-modal transport measures

MIM measures are mostly cost-intensive, require high use of technical systems, require low to moderate amount and scale of stakeholder's participation and are widely accepted by the public. Of a total of ten MIM measures, three measures qualified for first recommended measures (MIM-5, MIM-6 and MIM-7) and two measures qualified for second recommended measures (MIM-1 and MIM-2). Despite high effectiveness of the total five residual measures (MIM-3, MIM-4, MIM-8, MIM-9 and MIM-10), the measures indicated high costs involved in implementation, extensive requirement of use of technical systems, moderate to high involvement requirements of stakeholders and least difficulties of public acceptance.

Freight transport measures

The three selected FT measures qualified for the recommended list of TM measures (FT-1, FT-2 and FT-3). However, the assessment of measure 'City Logistics System' indicated high difficulties due to high costs and intense participation requirement of various stakeholders. The measure assessment also indicated moderate to high effectiveness of all selected measure.

In general, the traffic managers are responsible for planning, executing and assessing TM measures. Qualitative assessments are most commonly used by traffic managers due to its advantage of providing an immediate feedback. The knowledge of effective and readily applicable measures is important for traffic managers. Simultaneously the knowledge of other effective but non-applicable measures in existing local environment is also important for traffic managers. This knowledge engages the traffic mangers in improving the applicability of TM measures in order to include measures while the formulation of TM strategies.

7.5 Summary

This chapter has described the pre-selected twenty-seven traffic management measures which belong to five modes of transport and which can be applicable in the cases of disasters. The complimentary measures of all twenty-seven measures are also revealed. The given measures are well-integrated with the traffic management modules explained in earlier chapters. Similarly these traffic management measures will form the traffic management strategies in the next chapter.

Further, the qualitative assessment of selected measures have also been discussed and conducted. The methodology of the assessment includes (i) estimation of relative weight of importance of traffic management factors using AHP technique, (ii) self-assessment and rating of measures based on effectiveness and difficulty scales, (iii) determination of priority classes of measures based on qualitative assessment model which provided the first and second recommended measures, and (iv) determination of residual measures signifying low applicability.

The qualitative assessment model provided a framework to assess the effectiveness and difficulty of TM measures. Such an assessment is useful in the decision-making process for the selection of TM measures and their improvement of applicability. The results indicated that all selected measures qualified for their effectiveness and seven measures disqualified for their applicability.

Those measures that disqualified for the recommended measures were found very effective in fulfilling the goals and criteria of traffic management in cases of disasters e.g. Traffic & Disaster Information Service, Disaster Traffic Management Centre and Work-Zone Coordination & Management Centre. The results indicated that costs of implementation and requirement of advanced technical systems were found as main hindrances in the application of measures followed by the stakeholder participation. The public acceptance is the least difficult factor in the application of TM measures.

Although the residual measures were found inapplicable in the local environment yet these measures will be used in the formulation of strategies in the next chapters. Thus, the applicability improvement methods for residual measures are presumed to be existent in the local environment and these methods could be applied in order to reduce the difficulty of implementation of residual measures. Such applicability improvement methods will be discussed in later chapters.

8 Formulation of Traffic Management Strategies in Cases of Disasters

8.1 Introduction

In this chapter the traffic management strategies proposed for disaster cases are presented. The main purpose of the strategies is to fulfil the set disaster traffic management (DTM) goals and objectives. The DTM goals and objectives are derived from traffic management problems and issues especially in cases during disasters. The fulfilment of an individual TM objective may involve multiple strategies with minimum mutual conflicts with each other. The traffic managers in real-time disaster situations implement action plans (known as strategies) through the set of established mechanisms, referred to here as traffic management modules. In this study, traffic management modules are briefly described. The recognition of the type of traffic management modules makes the implementation of TM measures easier due to anticipated acknowledgement of necessary processes and resources.

An individual strategy may involve several traffic management modules for the implementation of an individual measure. Similarly, different measures form a single strategy for the fulfilment of a defined objective. The implementation of different strategies and measures may involve the same traffic management modules but the individual TM measure can be influenced to perform differently depending on the needs of a particular strategy through the available traffic management modules in the local transport development environment.

The formulation of a strategy consists of identifying the influence areas which are traffic demand reduction and the transport supply augmentation influence areas explained in previous chapters. The traffic demand influence area is mainly focused on avoiding, shifting and controlling traffic demand through five influence types:

- **to avoid or reduce unnecessary car-mobility**,
- **to increase the vehicle utilisation in road transport**,
- **to shift the use of individual motorised transport**,
- **to improve the spatial distribution of traffic volume**, and
- **to improve the temporal distribution of traffic volume**.

Similarly the transport supply influence area is mainly focused on improving the transport supply according to four influence types which are:

- **to improve the transport capacity and supply**,
- **to reduce the traffic accidents and its impacts**,
- **to improve integration between different activities**, and
- **to reduce the disturbances in traffic flow**.

The given nine influence types are included to cover the full range of disaster traffic management goals and objectives. The purpose and the functions of a traffic management strategy are defined by the different influence types in the influence areas of traffic demand and transport supply. A total of nine disaster traffic management strategies are formulated to influence both the traffic demand and transport supply during disasters.

8.2 Definitions

In order to follow the formulation of traffic management strategies, the following definitions are provided. A disaster traffic management strategy is ***a pre-defined action plan for the implementation of a set of traffic management measures to improve a specific disaster transport situation***. Following this definition of DTM strategy, a traffic management measure is defined as ***a desired realisation of an action that creates traffic impacts towards the desired improvement of a defined transport situation***. A strategy is implemented in real-life conditions through the identification of traffic management modules in the local environment of study area. ***A traffic management module is an established traffic influencing process or mechanism for the implementation of measures***.

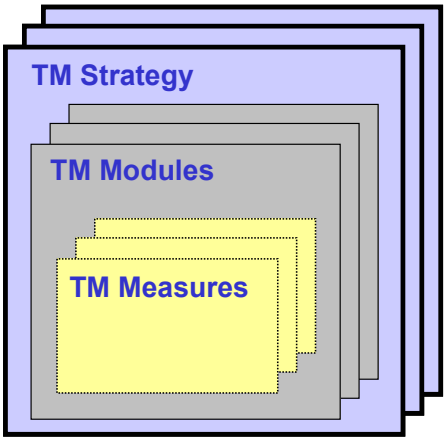


Figure 8-1: Illustration of relationships of TM Strategy, TM modules and TM measures

8.3 Traffic Management Strategies

The basis of the formulation of disaster traffic management strategies is the established disaster traffic management goals and objectives. The establishment of disaster TM goals and objectives is based on the transport situations in disasters. The disaster transport situation consists of: (i) traffic and transport problems due to disaster impacts on transport supply and traffic demand; (ii) the transport development state of the disaster affected area; (iii) traffic and transport operations performance.

Thus, a disaster traffic management strategy involves many individual traffic management modules for its implementation and success. The TM modules are aimed at implementing the traffic management measures and fulfilling the purpose of TM strategies. The TM measures could be influenced through the traffic management modules based on the requirements of a particular strategy. The fulfilment of an individual TM objective may involve multiple strategies, modules and measures that have minimum mutual conflicts between them.

A strategy can influence both the traffic demand and the transport supply. A total of nine TM strategies are formulated that cover a full range of TM objectives in disasters. The intended impacts of each TM Strategy on traffic demand and transport supply with a selection of possible measures are explained in the following sections.

The initial five strategies explained in the later sections are traffic demand reduction strategies and last four strategies are transport supply augmentation strategies.

Strategy to avoid or reduce unnecessary car-based mobility

Mobility is indispensably integrated in the today's society and economic processes. Mobility is an essential requirement to achieve a standard of living and for an economic growth. But in exceptional cases like disasters, there is often a need to trade-off mobility options due to the transport deficit and increased traffic demand. The unnecessary mobility is a non-urgent mobility which can be replaced or substituted by providing different transport modes, transport destinations and transport times and thereby facilitates the needs of urgent mobility. Mobility cannot be prevented completely and therefore mobility-reduction need not be an aim of any strategy. This strategy is instead focused on evolving new mechanisms when mobility is no longer necessary (more favourable land use) and by influencing the traffic demand to be more effective such as substitution by linking trips, substitution by technology and substitution by trip modification.

Possible measures of the strategy: Economic or preferential incentives and disincentives (alternate modes, destinations and times), Trip reduction ordinances (compulsory closing of public and private establishments, alternative or flexible work schedules) Land-use modification ordinances (temporary land-use zoning), Traffic and disaster information service, City logistics system (freight transport coordination schemes), Household goods delivery transport system (home shopping network).

Strategy to increase the vehicle utilisation of transport modes

This strategy increases the vehicle utilisation without increasing the traffic volume on the roads. This strategy addresses the basic problem of the low-occupancy vehicle usage in motorised transport modes in disasters. Strategy proposes the full usage of passenger and freight capacity of vehicles and suggests the interoperability of transport modes in view of high traffic demand and low transport supply.

Possible measures of the strategy: Economic or preferential incentives and disincentives (alternate modes, destinations and times), Carpooling and other ride-sharing programs (car-sharing schemes), Road section control (high occupancy vehicle lanes), Traffic and disaster information service, City logistics system (freight transport coordination schemes).

Strategy to shift the use of individual motorised transport

The reduction of car use as well as shifting the car use to other transport modes is an important strategy to overcome accidents, reduce pollution and improve the economy of transport operations. This strategy is used to either shift the use of car to other motorised propulsion-based transport modes such as trains and buses or non-motorised-propulsion based transport modes such as walking or cycling. The application of this strategy does not hinder mobility but its application recommends restrictions on the selection and use of individual motorised transport modes. The strategy also proposes the approach of using the inter-modal and multi-modal transport for the needs of mobility. In this strategy, inadequate road capacity problems are solved with effective utilisation of available capacities of alternative means of transport.

Possible measures of the strategy: Economic or preferential incentives and disincentives (alternate modes), Establishment of pedestrian routes and facilities, Establishment of bicycle routes and facilities, Road network control (automobile- restricted zones), Improvement of inter-modal and parking facilities (park and ride, park and share), Road section control (HOV lane management), Traffic and disaster information service (information kiosks).

Strategy to improve the spatial distribution of traffic volume

This strategy addresses the problem of congestion of road network due to a disproportionate use of the capacity of the road. A proportionate distribution of traffic on the network increases the transport capacity while decreasing the traffic congestion and related impacts on the affected corridors. This strategy can be applied to facilitate the priority of disaster-related emergency traffic due to ambulances, police and fire-brigade vehicles. The principle of vehicle segregation is used to segregate traffic based on needs of the road capacity for other priority traffic. Segregation of traffic includes both motorised traffic (vehicle to vehicle segregation) and non-motorised traffic (vehicle to pedestrian/bicycle segregation). Traffic management objectives; especially safety and environment objectives, are fulfilled by the application of this strategy. The spatial distribution of traffic affects the destination selection as well as the route selection by the road user. Thus, the selection of alternate routes and alternate destinations should be adequately compensated by equivalent benefits such as reduction of travel time. However there exists a problem to attain the collective optimum and individual optimum simultaneously.

Possible measures of the strategy: Economic or preferential incentives and disincentives (alternate routes and destinations), Land-use modification ordinances, Road network control (automobile-restricted zones, access restrictions and modes segregation), Improvement of signalised traffic control (traffic signal control), Improvement of non-signalised traffic control, Improvement of inter-modal and parking facilities (parking management), Traffic and disaster information service (commercial radio and television, dynamic message signs)

Strategy to improve the temporal distribution of traffic volume

This strategy addresses the issue related to inefficient temporal distribution of the traffic volume. High traffic volumes during certain times can lead to deficit of supply capacity on certain corridors due to concentration of disaster management activities. In cases where the infrastructure supply capacity is under utilised during non-peak periods, this strategy influences the time selection of road users to optimise the use of transport supply in disasters.

Possible measures of the strategy: Economic or preferential incentives and disincentives (alternative work schedules/flexible work schedules/compulsory closing of public and private establishments), Land-use modification ordinances, Freight traffic operations control (freight transport entry time restrictions), Special traffic rules enforcement (access restrictions), Improvement of signalised traffic control (traffic gating), Work- zone coordination and management centre (roadway maintenance management including weather management), Traffic and disaster information service (commercial radio and television, dynamic message signs)

Strategy to improve the transport supply capacity

This strategy primarily addresses the improvement of the transport infrastructure to increase the utilisation of available transport infrastructure and operation capacities. Thus, the strategy includes the operational and administrative measures to optimally utilise the transport capacity. The construction of new infrastructure is ruled out in this strategy except for minor construction, repair and maintenance of existing infrastructure. The infrastructure is improved for all transport modes by addition to the vehicle fleet for all transport modes, establishment of routes for pedestrians and cyclists, development of missing links and the use of existing non-designed transport spaces for transport purposes.

Possible measures of the strategy: Special disaster transport services (agreements on transport service operations), Land-use modification ordinances (temporary land-use zoning) Public transport network improvement (extension and modification of routes), Public transport scheduling improvement (vehicle rotation plans), Public transport accessibility improvement (feeder services, pedestrian and bicycle routes), Public transport capacity improvement (additional wagons), Road network control, Road section control, Traffic and disaster information service, Work- zone coordination and management centre.

Strategy to reduce traffic accidents and their impacts

This strategy addresses the traffic and transport issues related to traffic accidents which cause multiple disturbances in traffic and reduce the capacity of the transport infrastructure. Therefore the strategy is intended to reduce both the occurrences of traffic accidents and the negative impacts of traffic accidents on the traffic flow.

Possible measures of the strategy: Special traffic rules enforcement (vehicle improvement), Improvement of signalised traffic control (emergency vehicle priority) Improvement of non-signalised traffic control (speed control, visibility enhancement), Traffic and disaster information service (traffic message channel, disaster training and exercises, traffic education and public awareness), Work- zone coordination and management centre (roadway maintenance management including weather management, information management).

Strategy to improve integration between traffic-related activities

This strategy adopts a multidisciplinary approach to maximise the efficiency of existing transport systems. Three main characteristics of this strategy are acknowledged. The first main characteristic of this strategy is the integration of modes by synchronising the travel time tables of various transport modes. The second important characteristic of this strategy is the change of designated use of modes for maximising the vehicle capacity and minimising the empty fleet (interoperable transport). The third important characteristic of this strategy is the integration of various activities to minimise the traffic demand and maximise the resource utilisation. The synergy effects of this coordination are important for the traffic management. Multi-tasking of activities and modification of roles of traffic management are some examples of this strategy implementation.

Possible measures of the strategy: Public transport scheduling improvement (synchronised travel time tables), Trip reduction ordinances (inter-operable transport, trip chaining) Work- zone coordination and management centre (manual traffic control), Disaster traffic management centre (disaster site traffic control, roadway maintenance), Traffic and disaster information service (pre-trip and en-route information)

Strategy to reduce the disturbances of traffic flow

This strategy is implemented to reduce the disturbances in traffic flow which originate from sources other than from construction sites, roadway maintenance services and accidents. The strategy includes disturbances in the traffic flow which could be due to prevailing weather conditions during disasters (rain, snow), poor driving behaviour (sudden braking or other technical reasons) and non-incident related vehicle breakdowns among other similar sources of traffic flow disturbances. This strategy also reduces the consequences of disturbances on traffic flow.

Possible measures of the strategy: Special traffic rules enforcement (vehicle improvement, speed limits), Road section control (lane management, speed zoning) Improvement of signalised traffic control (traffic signal control), Improvement of non-signalised traffic control (visibility enhancement), Work- zone coordination and management centre (accident and incident management, roadway maintenance management), Traffic and disaster information service (In-vehicle traffic information and route guidance, disaster training and exercises),

8.4 Summary

Traffic Management in disasters will continue to gain significance in the future and will be an important area in order to achieve the functions of disaster management. The explained strategies in this chapter provide a framework for the development of more strategies in disasters. The formulated strategies could well be integrated with the traffic management modules and the existing traffic management measures in the disaster-affected or disaster-prone region. The success of traffic management and thereby disaster management can be achieved if all the influence types of the strategies are properly addressed and current modules and measures are effective. In cases where the intended influences are not met, the formulated strategies can provide framework of innovative attempts for the development of necessary modules and measures.

9 Scenario Development for Traffic Management in Cases of Disasters

9.1 Introduction

The development of scenarios is quite common to planning disciplines including urban transport planning. The traffic managers of large cities face great challenges in providing a quick transport response to the disaster support functions which are crucial to the livelihoods and safety of thousands of people. Naturally the disaster managers including traffic managers need to possess decision tools and models to proactively prepare for disaster response and recovery. Scenario planning technique is an effective tool which can be used to analyse possible scenarios of disaster traffic management. Scenario planning is largely based on the determination and assumption of facts of key local factors in the macro environment. Scenario planning can be used to both develop and analyse traffic management scenarios of disasters. When developed, the scenarios are used to appraise the traffic management preparedness. The developed scenarios are also used for validation of the formulated disaster traffic management strategies in earlier chapters. In this regard, this chapter presents a framework for the application of scenario planning techniques for disaster traffic management purposes.

9.2 Application of Scenario Planning Process

Scenario planning is a part of the strategic planning process that organisations use to analyse plausible futures in order to make strategic decisions. The basis of scenario planning is the identification of various factors (inputs) that influence the focal decision. The scenario planning technique could be very effective in disaster risk analysis with respect to traffic management situation. In disaster traffic management, these factors are related to the state of transport supply, transport demand, transport development and the transport performance. The scenario planning is often mistaken as a future predication tool but in reality it is a tool for strategic analysis and decision making. Scenario planning enables organisations to optimise the resource allocation for complex situations with an uncertain future.

Scenario planning may involve qualitative judgements that are difficult to quantify, such as subjective interpretations of facts, shift in values, new regulations and/or inventions. The important key local factors of transport in disaster area (general inputs) are mainly dependent on influencing in the macro environment. The macro environment is described by the following five factors (abbreviated as **STEEP**):

- **Social development state,**
- **Technological development state,**
- **Environmental development state,**
- **Economic development state,** and
- **Political and administrative development state**.

In transport discipline, the term traffic management scenario is defined as the combination of transport situation and the traffic management strategies (Figure 9-3). The transport situation for disaster traffic management is described by the following three factors:

- **Disaster impacts on transport supply and demand,**

- **Transport development state of the disaster area,** and
- **Transport operations performance during disasters.**

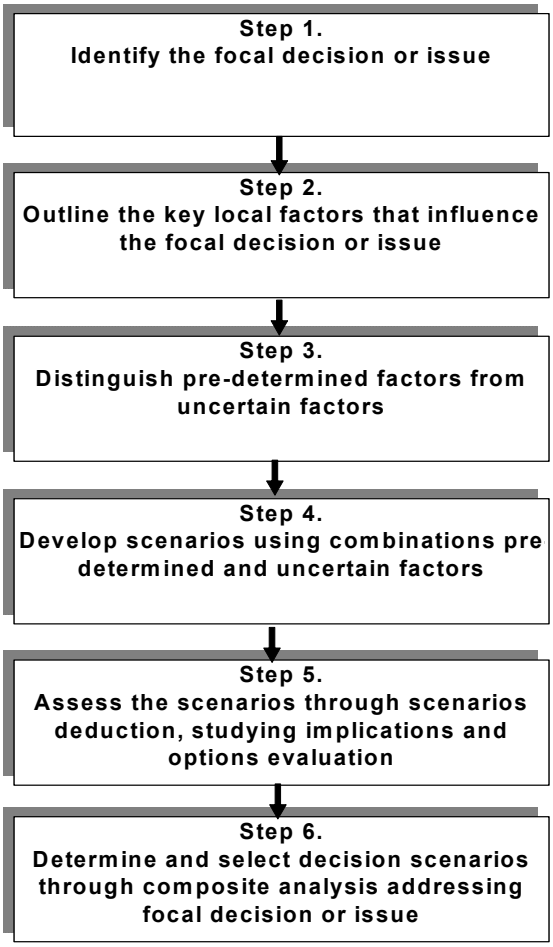


Figure 9-1: Scenario planning process (adapted from Schwartz, 1991)

The traffic management strategy is described by a group of basic and complimentary traffic management measures enforceable in the disaster environment (see Figure 9-3). Thus, the traffic management scenarios in disasters can be assessed based on the disaster transport situation and the corresponding disaster traffic management measures of the strategies.

The application of scenario planning technique for the disaster traffic management offers the following benefits:

- It is applicable to both urban and inter-urban areas. Hence it can be tested for various future alternatives of transport at city and state level.
- It provides an analytical framework and process for understanding complex issues concerning traffic management in disasters.
- It provides an enhanced decision making framework for transport situation in disasters.
- It supports the traffic management by providing various opportunities in cases of limited transport resources in disasters.
- It is a low cost tool available to transport planners compared to expensive simulation and training exercises.
- It is a less time consuming exercise compared to skills and training exercises.

- It is highly efficient in decision making due to improvement through iterations.
- It assesses the core competencies of the organisation and the key success factors for verifying the transport system resiliency in disasters. It provides proposals to eliminate problems, issues or processes that contribute to inefficiency of transport.

The scenario planning process with respect to the traffic management is explained in six steps (see Figure 9-1):

- **Step 1. Identify the focal decision or issue**

This step is aimed at discovering the focal decision or issue for which the scenario planning is applied. Given the criticality and importance of the focal decision or issue in disasters, it is necessary to involve all stakeholders of disaster management in the decision making process. The developed transport scenario may not always be focal-decision oriented. Eventually, the developed scenarios may also be used to explore the possible transport situations and traffic management strategies relevant for disasters. Thus, the application of scenario planning provides either decision-based scenarios or exploratory scenarios. The scenario planning for disaster traffic management determines the following:

- The possible disaster transport situation.
- The possible disaster traffic management measures.
- The effectiveness of traffic management measures for a particular transport situation in disasters.
- The applicability of traffic management measures for a particular transport situation in disasters.
- The identification of key factors those are responsible for the ineffectiveness and inapplicability of measures for a particular transport situation in disasters.

It is important to set a time frame e.g. 5-10 years for which the focal decisions will be relevant in the scenario planning process. The set time frame would also limit the identification and selection of key local factors in the next step. The time frame and the other limitations of the focal decision mainly depend on the requirements of the study.

- **Step 2. Outline of key local factors that influence the focal decision**

This step consists of identification of the key local factors that influence the performance of the formulated traffic management strategies (focal decision). It is important to consider only those key local factors which are confined and are important to the focal decision. This step limits the key local factors to a discipline, location, country, organisation and other factors described by local characteristics e.g. demography, level of congestion, land use and modal split. The determination of key local factors normally requires scenario thinking and extensive brainstorming sessions of teams. The factors that influence the focal decision or issue are distinguished in a macro-environment. The macro-environment influence on the key local factors is categorised by social, technological, economic, environmental and political development state of the disaster study area. This categorisation is necessary in cases of macro-level scenario analysis but the micro-level scenario analysis might exclude them. The categorisation of key local factors in the macro environment assists in making the decisions about the activation and implementation of traffic management modules and strategies.

The key local factors whether predetermined or undetermined are identified and selected in this step. Transport planners using scenario planning need to identify various local input factors that affect the transportation system during disasters. This step of the process also exhibits the inter-relationships between the selected local input factors.

Within three situation assessment modules, a total of ten key local factors were identified. The suitable criteria have been used to describe the 10 key local factors. Several indicators could be used to describe the key local factors (situation factors) as shown in Table 9-1. The first assessment module clearly indicates two key local factors; that are the disaster impacts on transport supply and the disaster impacts on traffic demand. The transport supply condition could be explained through the following criteria:

- The disaster impact on transport infrastructure,
- The disaster impact on transport modes and, and
- The disaster impact on transport users or operators.

Similarly, the characteristics of disaster traffic demand could be explained through four criteria, which are:

- The magnitude of transport demand,
- The type of activities generating transport demand,
- The total duration of activities generating transport demand, and
- The origin and destination (total coverage area) of trips.

The key local factors of transport demand are indicative of activation of disaster support functions and therefore the transport demand in response and recovery phases of disaster management. The transport development state and transport operations performance criteria are given in the Table 9-1.

The availability of the data both qualitative and quantitative that describes the predetermined and undetermined factors of scenario is necessary for the scenario analysis. A proper attention is required to prevent the exclusion of any undetermined or predetermined factors on the basis of unavailability of data.

- **Step 3. Distinguishing predetermined factors from undetermined factors**

The third step involves the differentiation of the predetermined factors from the undetermined factors. The estimation of degree of uncertainty serves an important basis to distinguish the undetermined factors from the predetermined factors. The predetermined factors are fixed by system conditions which could be predicted with an acceptable degree of certainty. The predetermined factors are generally inevitable and are impossible to influence within the time frame of scenario analysis. The transport development state and the applicable traffic management strategies are considered as predetermined factors for the purpose of this study (see Figure 9-2).

The undetermined factors are normally independent of predetermined factors. The undetermined factors are not fixed by the system conditions such as current transport development state or the applicable traffic management strategies. However, in some cases the degree of uncertainty of undetermined factors can be reduced by establishing their inter-relationships with the determined factors (explained in later section on interrelationships). Consequently, the reduction in the number of crucial undetermined factors reduces effort and improves the quality of scenario analysis. The

understanding of inter-relationships is also useful for checking the consistency and plausibility of the possible scenarios.

It is important to understand that the segregation of undetermined factors from the predetermined factors is based on the uncertainty and not on the hindrances of data collection e.g. unavailability of data or data collecting techniques. The data collection techniques of uncertain data could be available yet the factors remain undetermined due to unknown characteristics of system conditions. The factors related to transport operations performance are considered undetermined factors due to unknown characteristics of system condition (value or intensities) even when the criteria data e.g. fleet utilisation, capacity, and skill level data assimilation techniques exists.

This step also involves the reduction of unimportant factors (predetermined and undetermined) based on their relevance to scenario analysis. The factors can be reduced by two practices:

- Assigning certainty to undetermined factors by establishing inter-relationship with predetermined factors,
- Introducing scenario logics e.g. time-frame, stakeholder's participation level, involved costs, etc. Such practices limit the impossible extreme scenario development.
- **Step 4. Develop scenarios**

The scenarios are developed by combining the predetermined factors and the critical undetermined factors. The uncertainties of critical undetermined factors of transport in disasters are due to:

- Traffic problems resulting from unknown disaster impacts on transport supply and traffic demand,
- Relatively unknown transport development state during disaster, and
- Relatively unknown transport operation performance.

The predetermined factors of transport in disasters are mostly the applicable traffic management strategies in the current transport development state. In this step the static traffic management strategies are checked for effectiveness and applicability in hypothetical disaster transport situation to yield traffic management scenarios.

A two-axis grid of disaster transport situation and disaster transport strategies will provide the possible scenarios of transport in disasters. It is important to describe the selected scenarios (2 to 4 scenarios) in detail. One approach to developing transport scenarios may be to segregate the negative factors and positive factors to give definitions of a scenario (best or worst case scenarios). The positive and negative factors can be combined based on intuitive or realistic judgements to exhibit more possible extreme scenarios.

It is important to document the selected scenarios for further analysis such as simulation exercises. The documentation on scenarios needs to present the basis in support of inclusion of predetermined and uncertain factors for each individual scenario.

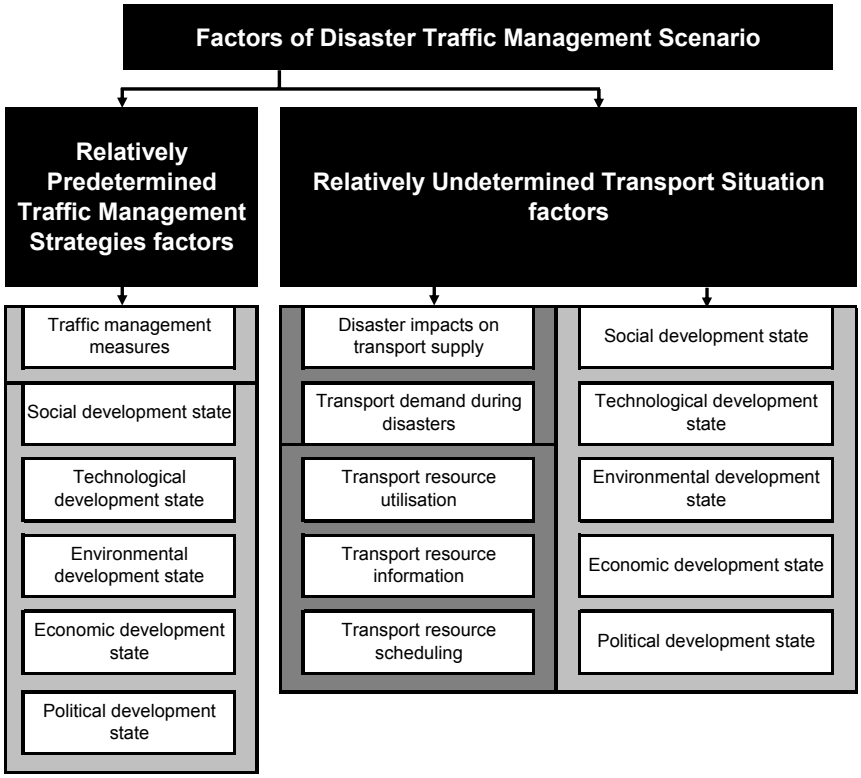


Figure 9-2: Illustration of predetermined and undetermined factors

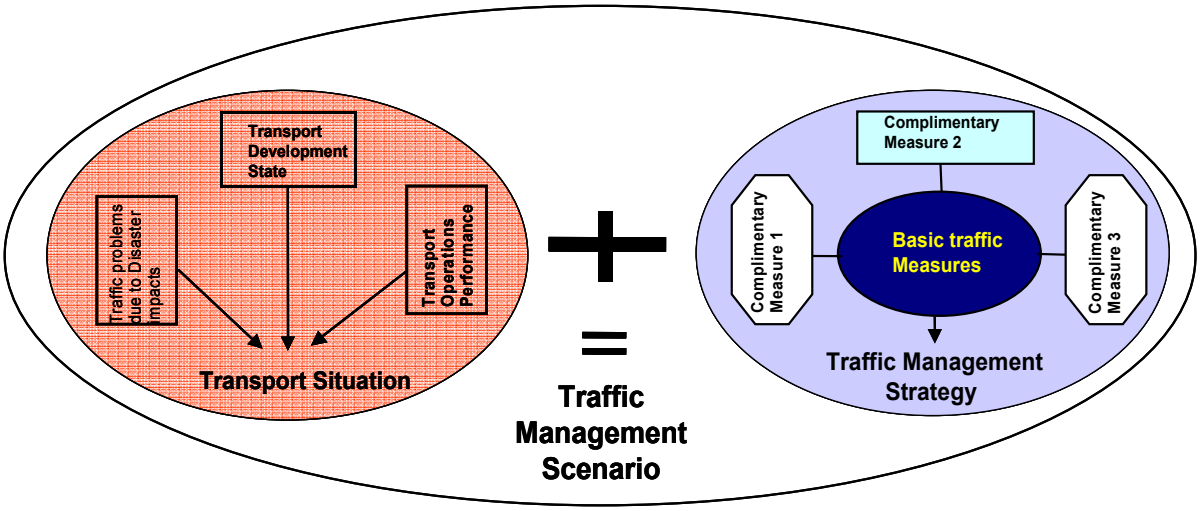


Figure 9-3: Illustration of traffic management scenario development

- **Step 5. Assess the scenarios**

In this step, the scenarios are assessed by analysing the implications between predetermined factors (transport and non-transport elements) and critical undetermined factors (transport and non-transport strategies). Importantly, the application of scenario planning technique for disaster traffic management is meant for improving decision making by revealing the vulnerabilities that might exist in the current traffic management system. The scenarios are assessed for their relevance to achieve the goals of the focal decision. They need to be checked for consistency and stable outcome solutions.

Transport planners can assess different scenarios based on the transport situation assessment and traffic management strategy assessment. The indicators of key local factors will provide the inclusion of a scenario as decision scenario. Traffic simulation offers the option to transport planners to change the inputs of indicators and hence improve scenario analysis. Simulation techniques are used to check the plausibility of scenarios and also check the effectiveness of traffic management measures (strategies). It is helpful to develop the quantitative methods of assessing the scenarios which help quantify consequences of various transport scenarios such as on transport related accidents (translated to deaths and injuries), traffic congestion induced delay, transport costs and traffic pollution.

- **Step 6. Select decision scenarios**

Scenario planning is an iterative process. The above steps are iterated until the focal decisions of the organisation are addressed. It is important to select a few indicators that assist in monitoring or assessing scenarios to determine decision scenario. The aim of the decision scenario is to present the vulnerabilities of the current transport system by appraisal of the following:

- Transport situation in disaster,
- Implementable disaster traffic management strategies,
- Inapplicable traffic management strategies, and
- The basis of inapplicability of traffic management strategies.

Decision scenarios are used by many stakeholders of disaster and traffic management to provide development orientation. The results of decision scenarios will initiate many changes in transport industry, transport organisation, transport operation, transport politics, transport authorities and transport research. Decision scenarios will emphasise on key thrust areas e.g. disaster traffic management preparedness, institutional coordination, alternate equipments and technologies, traffic education and training. Decision scenarios will provide for possible TM strategies to increase the resilience and redundancy of transport in disasters.

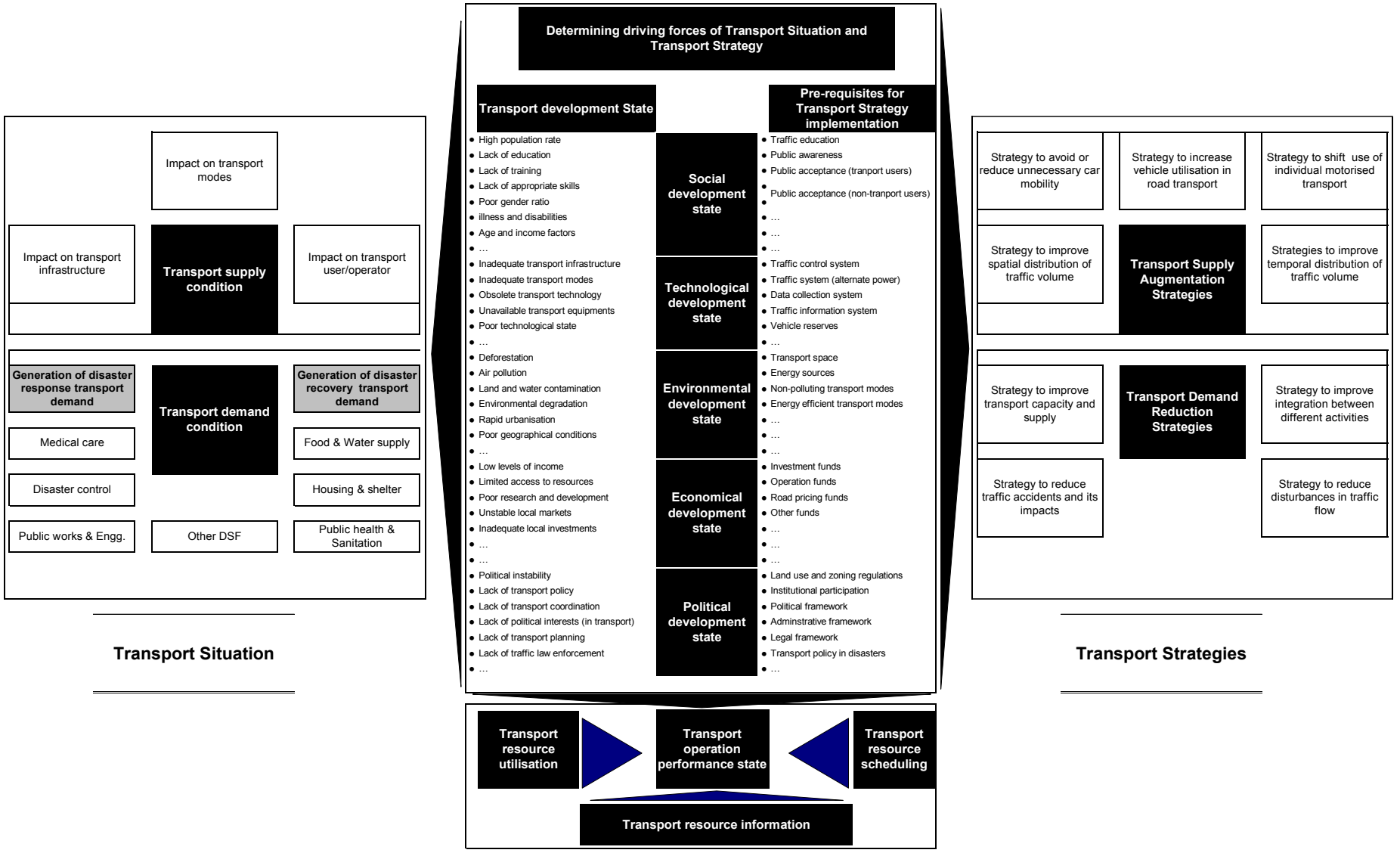


Figure 9-4: Possible relationships for scenario development

9.3 Assessment of Disaster Transport Situation

Introduction

The complexities of varying disaster related transport situations and traffic management strategies make it necessary to develop tools for strategic analysis in order to enhance the transport system performance. The scenario planning technique is a decision making tool that could be implemented to assist the traffic management during disasters. The development of disaster traffic management scenarios requires the assessment of disaster transport situation and the corresponding transport strategies (group of measures) in the local environment. There are three disaster situation modules used for the assessment of disaster traffic situation:

- Disaster impact on transport supply and demand: The impact signifies the damage potential and the traffic demand generation potential.
- Transport development state: The prevailing transport development state which is independent of the disaster impacts but dependent on the local disaster area or disaster-prone characteristics.
- Transport operations performance: The performance is dependent on the disaster impacts and the local disaster area or disaster-prone area characteristics.

These three assessment factors for purposes of scenario development are considered to be uncertain factors due to lack of knowledge and precision in estimating the various disaster impacts upon the transport system. In order to follow the concept of scenario planning, the following terms are defined:(i) **Transport situation assessment modules**: An assemblage of transport situation factors regarded as a single unit or having some unifying relationship; (ii) **Transport situation factor**: The transport cause that contributes to the development of the transport situation; (iii) **Indicators**: A small set of transport or non-transport data used for the estimation of the transport factors, (iv) **Data**: The units of information including perceptions, numbers, observations, facts or figures; and **Information**: The “useful data” which is meaningful, relevant and understandable to the user and non-user for particular purposes.

The scenario development pertaining to disaster traffic management includes assessing the disaster transport situation and the disaster traffic management strategies of the disaster study area. In the next sections transport situation and traffic management strategies assessments are made. The assessments are done using mainly qualitative data. In the transport situation assessment, the level of situation is an indicative of good or bad disaster transport situation. In the traffic management strategies assessment, strategies are assessed for their effectiveness and applicability in various disaster situations. The cumulative scores of strategy assessment are indicative of an effective or a non effective disaster traffic management strategy. The various transport situations and transport strategies are combined to build possible traffic management scenarios using the principles of scenario planning for the improvement of traffic management (see Figure 9-3 and Figure 9-4).

Transport situation assessment modules	Transport situation factors of assessment	Criteria of assessment	Indicators of assessment
Assessment of disaster impacts on transport supply and demand	Transport supply condition	Impact on roads, terminals and traffic control devices	Area (km^2) , Length (Kms), Number/ %, of roads damaged or non-functional
		Impact on vehicles	Number/% of vehicles damaged or non-functional
		Impact on transport user and operator	Number/% of affected transport users and operators
	Transport demand condition	Magnitude of trips	Number/% of passenger trips, person-trips, freight trips, service trips, etc.
		Trip purpose	% distribution by trip purposes (disaster control,construction,etc.)
		Trip duration	Total activation duration (hours, days and months) of each disaster management function
		Trip distance	% distribution by trip distances and purposes (passenger-km, vehicle-km, tonne-km)
Assessment of transport development state of the disaster area	Social development state	Physical disabilities	% of population by illnesses and disabilities
		Educational disabilities	% of population by literacy
		Personal disabilities	% of population by age, gender, language religion, income, etc.
	Technolgical development state	State of transport infrastructure development	% distribution of metalled roads by type, Number of cars or 2-wheelers per 1000 inhabitants, modal split, etc.
		State of traffic control technology	% manual/automatic/intelligent traffic control, etc.
		State of vehicle technology	% vehicle by age, passenger capacity, engine and emission technology, etc.
	Environmental development state	Physiographic state	% of inaccessible area due to level/hilly/transition terrain, slope, altitude etc.
		Climatic state	Rainfall (mm/yr), snow (mm), temperature (^OC), wind speed (Kmph), air pollution (% gas emissions by transport sector), etc.
		Built environment state	Population density (people per km^2), land use distributions (% land by sectors), % of urban population (urbanisation level), etc.
	Economic development state	Economic state of population	Transport expenditure per person/ per vehicle/ per vehicle-km, % of population by income groups (LIG,MIG,HIG), etc.
		Economic state of State	Transport expenditure(budget), GDP per total population of State etc.
		Economic state of Nation	Gross domestic product, total expenditure (budget) on transport research and development, etc.
	Political and administrative development state	Political and administrative attitudes	Political attitudes (attitudinal surveys), number of joint ventures, people/offices/ngo's per DMF, etc.
		Political stability	Total terms and time spent in Office
		Enforceability of laws and regulations	Revenue earnings from traffic offences, % traffic violations by type, etc.
Assessement of transport operations performance	Transport resource utilisation	Fleet utilisation level	Average vehicle occupancy, passenger-km or tonne-km per unit of transport service, load factors ,empty haulage, etc.
		Capacity utilisation level	Arterial and freeway LOS (% E &F), vehicle km per lane, ratio of traffic volume to service flow etc.
		Skills utilisation level	Total staff per licensed vehicle, manhours per unit activity (Staff productivity), etc.
	Transport resource information	Transport information level of users	% user satisfaction with transport information, Number or % of informed people, etc.
		Transport information level of non-users	% reduction of total traffic with transport information, % shift in peak hour traffic due to information, etc.
		Transport information level of operators	% of multi-purpose trips, % of linked trips, % reduction in trips, Stakeholders participation level, etc.
	Transport resource scheduling	Transport service regularity	Duration of transport services in hours, days and months
		Transport service punctuality	% arrival delays, % departure delays, etc.
		Transport service sequence	% of linked trips per tranist route/operation time/transport service, transfer time, donation-to-delivery time, delay reduction, etc.

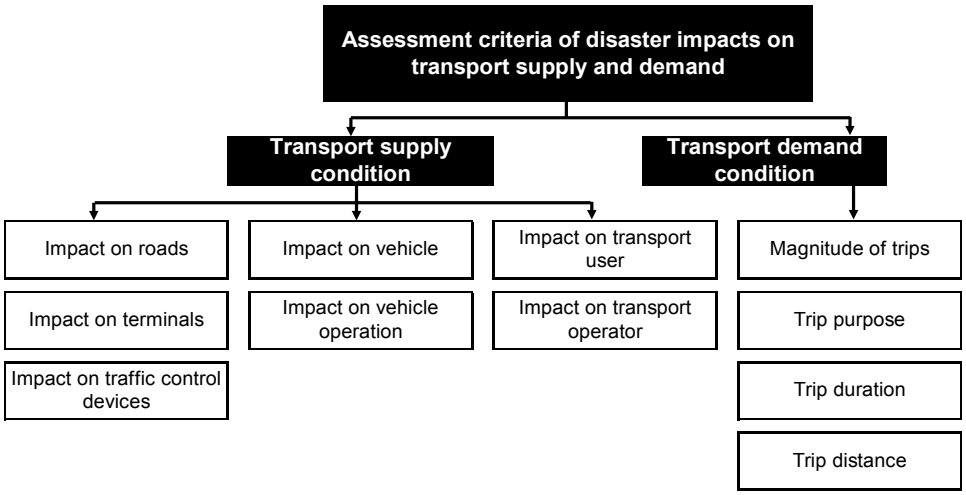
Table 9-1: Description of disaster transport situation

The factors used for the disaster situation assessment are inter-connected and it is difficult to state the cause of transport situation with one single factor. Therefore all the factors are considered equally relevant in the development of disaster transport situation and will be reviewed as individual factors with no bearing on the other for the purposes of this study. Table 9-1 indicates the disaster transport situation factors used for the assessment. The following sections describe

the key influencing factors described by indicators based on a certain criteria. The indicators help in assessing the good or bad state of the factors related to transport situation or transport strategy.

Assessment of disaster impacts on transport supply and traffic demand

The development of a traffic management scenario necessitates the estimation of disaster impacts on both transport supply and traffic demand. This assessment will evaluate the level of transport damage and transport demand generation for disasters. The assessment involves qualitative and quantitative data (assumptions and facts) about the disaster impacts on transport supply based on knowledge of the disaster characteristics and disaster management process.



Note: The above given transport supply and transport demand criteria are indicative only.

Figure 9-5: Criteria to assess disaster impacts on transport supply and demand

The evaluation indicators of disaster impacts for transport supply are based on three criteria, which are the impacts to:

- Road transport infrastructure,
- Transport modes, and
- Transport users (operators).

The criteria of damage of road transport infrastructure include all roads, bridges, culverts, subways, terminals, traffic control devices, etc. measured in terms of area, length and number of roads damaged or in-operational. The criteria of impact on vehicle include all transport modes, measured in terms of number of vehicle in-operational. The criteria of impact on transport user and operator include the affected transport users and operators, measured as the number of people (users and operators) whose decision-making is affected. The assessment based on the above criteria will indicate the available transport supply condition after the impacts of a disaster (see Figure 9-5).

Situation Factors	Level of Situation	Grades	Situation Description	Situation Rating	Relative Weight
Transport supply condition	High Transport Supply Impact	3	This disaster causes extensive damage to roads, terminals, traffic control devices, vehicles, and/or will severly affect the decision making of transport users and operators.	*Please state your situation rate here*	*Please state your importance of the situation factor here*
	Medium Transport Supply Impact	2	This disaster causes substantial damage to roads, terminals, traffic control devices, vehicles and/or poor decision making among transport users and operators.		
	Minor Transport Supply Impact	1	This disaster causes minor damage to roads, terminals, traffic control devices, vehicles and/or slightly affects decision making among transport users and operators.		
	No Impact	0	The disaster creates no impact on transport supply characteristics.		
Transport demand condition	High Transport Demand Impact	3	This disaster generates very high magnitude of trips, large variations in trip purposes, trip duration and/or trip distances due to activation of most of disaster support functions.	*Please state your situation rate here*	*Please state your importance of the situation factor here*
	Medium Transport Demand Impact	2	This disaster generates high magnitude of trips, moderate variations in trip purposes, trip duration and/or trip distances due to activation of some disaster support functions.		
	Low Transport Demand Impact	1	This disaster generates relatively low magnitude of trips, less variations in trip purposes, trip duration and/or trip distances due to activation of a few disaster support functions.		
	No Transport Demand Impact	0	The disaster causes negligible impact on transport demand characteristics.		

Note :1)The situation rating should be based on scale, intensity and type of disaster impact on transport supply(given in table) and demand.
2)The situation rating may involve either an individual criterion or a combination of different criteria based on data availability.
3)The value of different indicators of situation factors based on certain criteria could be used to rationalise the situation rating.
4)The upper and lower values of indicators could be set according to the disaster characteristics.
5)The situation rating should be based on inter-relationships between different situation factors.
6)The situation rating given above is always relative, with higher grades representing more negative.

Table 9-2: Description of disaster transport situation (Transport Supply and Demand)

The knowledge of disaster characteristics and the disaster management process is also required to determine the total transport demand. The evaluation indicators of transport demand condition are primarily based on four criteria:

- The magnitude of trips,
- Trip purposes (based on various activities of DMF),
- Trip duration (based on various activities of DMF), and
- Trips distances.

The criteria of magnitude of trips include trips which are generated due to disaster- related or non-disaster related activities, measured in number of person-trips, number of freight-trips, etc.

The criteria of trip purpose include all activities of activated disaster support functions, measured in terms of degree of activation of a disaster support function (DSF), number of DSF activated, etc.

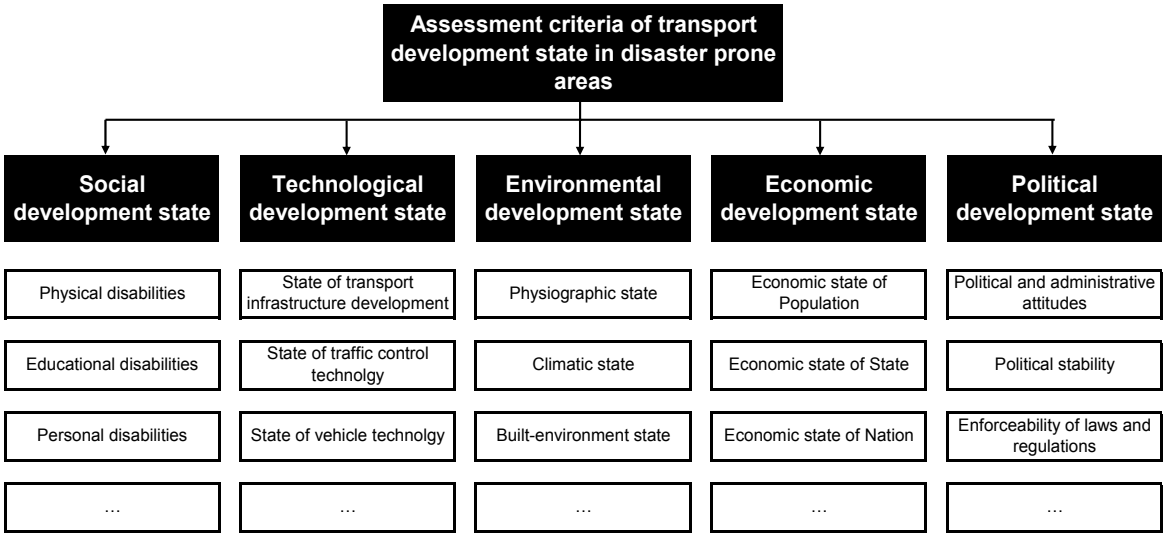
The criteria of trip duration include the respective duration of trips of each DSF, measured in terms of total activation time expressed in hours, days or months of various DSF.

The criteria of trip distance include the respective area coverage of each DSF, measured in passenger kilometres, vehicle-kilometres, tonne-kilometres, etc. The details on trip purposes, and trip origin and destination (trip O/D's) assist the decision-making of the type of traffic management.

The possible scenarios could be developed by combining various levels of disaster impact on transport supply and transport demand generation.

Assessment of transport development state

In order to assess the disaster transport situation, it is necessary to estimate the prevailing transport development state in the local conditions of a disaster prone area. The indicators that describe the transport development state are based on macro-level factors such as social, technological, environmental, economic and political.



Note: The above given transport development indicators are incomplete and indicative only.

Figure 9-6: Criteria to assess of transport development state

The estimation of the transport development state is required for the following reasons:

- To estimate the mobility disabled population to acknowledge the needs of mobility disabled people and application of traffic management.
- To estimate the infrastructure and technology availability for the traffic management purposes.
- To estimate the accessibility problems due to physiographic, climatic and built-up features, those pose challenges to traffic management.
- To estimate the economic conditions of people, state and government for the need of incentives and availability of funds for traffic management.
- To estimate the coordination, acceptance and enforcement conditions for the traffic management purposes.

Although the interrelationships between disaster impacts and the transport development state are quite evident, the indicators to describe transport development state are deemed external for the purposes of this study. The factors are cited below with some corresponding indicators:

Social development state: The evaluation indicators of the social development state are based on the three criteria of (i) **physical state**, (ii) **educational state** and (iii) **personal state of population**.

The criteria of physical state include the population with physical disabilities and illnesses are measured in percentage population by different types of physical disabilities.

The criteria of educational state include the population with educational disabilities and they are measured in percentage of illiterate population (traffic and other education).

The criteria of personal state include all people with personal disabilities; they are measured in percentage population by vulnerable age, gender, foreign language barrier, religion barriers, income, etc.

It is important to consider the social development state as it affects mobility due to the stated transport disadvantages that pose challenges to traffic management. Thus, traffic management

need to include the social issues related to impaired mobility and address them in stated goals and stated objectives.

Technological development state: The evaluation indicators of the technological state are based on the three criteria of (i) **state of transport infrastructure development**, (ii) **state of traffic control technology** and (iii) **the state of vehicle technology**.

The criteria of the state of the transport infrastructure include the state of road transport infrastructure, vehicle ownership patterns, etc. and they are measured as quality of transport infrastructure, vehicle ownership and modal split.

The criteria of state of traffic control technology include the type of traffic control technology available in the disaster-affected or disaster-prone area and they are measured in percentage of manual, automatic and intelligent traffic control.

The criteria of the state of vehicle technology include the type of vehicle technology and they are measured in terms of passenger capacity, vehicle condition (age, injection and emission condition), etc.

It is important to consider the technological development state as it affects accessibility and mobility, safety, environment, and economy of the disaster-affected area. Thus, traffic management in disasters need to develop measures which are applicable to the current technological development state of the disaster region.

Environmental development state: The evaluation indicators of the environmental state are based on three criteria: (i) **physiographic state** (ii) **climatic state** and (iii) **the built-up environment state of the disaster-prone or disaster-affected area**.

The criteria of physiographic state include all physiographic features of the disaster prone or affected area, and they are measured in terms of inaccessible area.

The criteria of climatic state includes all climatic factors which poses threat to traffic management, and they are measured in amount of rainfall, snow, temperature, wind speeds, air pollution and noise pollution among other factors.

The criteria of built-up environment state include all built-up environmental features, and they are measured in terms of population density, urbanisation levels, land use distributions, etc.

It is important to consider the environment development state as it affects rate, location, construction type and technology involved in transport development. The traffic management measures need to be applicable to the current physiographic, climatic and built-up environment state of the disaster region.

Economic development state: The evaluation indicators of economic state are based on the three criteria of (i) **economic state of population**, (ii) **economic state of the State** and (iii) **the economic state of the Nation**.

The criteria of economic state of population include all economic options available with the population, and they are measured as transport affordability expressed in terms of transport expenditure per person, per vehicle, per vehicle-km, etc.

The economic state of the State includes all economic options available to the disaster-affected or disaster-prone State, and they are measured in percentage of transport budget with the State.

The criteria of economic state of the Nation include all economic options available with the disaster-affected or disaster-prone Nation, and they are measured in terms of total budget of transport.

It is important to consider the economic development state as it affects the procurement of traffic management resources necessary in disaster management. Thus, traffic management need to conform to the economic condition of people, State and Nation of the disaster region.

Political and administrative development state: The evaluation indicators of political and administrative development state are based on the following criteria: (i) **political and administrative attitudes**, (ii) **political stability**, and (iii) **enforceability of laws and regulations**.

The criteria of political and administrative attitudes include attitudes of various political and administrative stakeholders of disaster management, and they are measured as participation rate of stakeholders. This signifies the cooperation amongst various disaster management stakeholders at the political and the administrative levels.

The criteria of political stability include the time spent by the ruling party in office, and they are measured in total length and time of years in office. This signifies the implementation environment and the experience of the ruling party with respect to the development, implementation, and political acceptance of new laws and policies necessary for successful disaster management. Political stability is thus an important criterion for assessing the implementation of new laws pertaining to traffic management.

The criteria of enforceability of laws and regulations include all activities to ensure the applicability of laws and regulations, and are measured in total revenue collection due to transport offences. This signifies the judicial arrangements for implementation of new laws and regulations pertaining to traffic management.

It is important to consider the political and the administrative development state as it affects both the mobilisation and the optimisation of deficient transport resources during disasters. It is therefore necessary for the success of traffic management that the measures employed are widely acceptable.

In order to find the challenges posed to disaster traffic management, an evaluation of the inter-relationships between the key factors is required. This section focuses on evaluating the inter-relationships with respect to the transport development state of the disaster-affected or disaster-prone region. The impact of the transport development on the key factors is described as ‘major impact’, ‘moderate impact’ and ‘insignificant or no established impact’. The impact of one factor on the other is considered in terms of mutually supportive or mutually conflicting.

The scenario description of Tsunami disaster in the southern state of Tamil Nadu, Nagapattinam, is explained in the Annexure F. The scenario description is based on the evaluation of different states described above in this section such as social, technological, environmental, economic and political state of Nagapattinam town.

Situation Factors	Level of Situation	Grades	Situation Description	Situation Rating	Relative Weight
Social development state	**Highly Unfavourable**	**3**	The disaster area exhibits a very large population with physical illnesses, illiteracy and personal disabilities due to age, gender, language, religion, etc.	*Please state your situation rate here*	*Please state your importance of the situation factor here*
	Moderately Unfavourable	**2**	The disaster area exhibits a substantial population with with physical illnesses, illiteracy and personal disabilities due to age, gender, language, religion, etc.		
	Slightly Unfavourable	**1**	The disaster area exhibits a lower but still considerable population with with physical illnesses, illiteracy and personal disabilities due to age, gender, language, religion, etc.		
	Favourable	**0**	The disaster area exhibits a negligible population with physical, educational and personal disabilities.		
Technolgical development state	**Highly Unfavourable**	**3**	The disaster area exhibits an extremely poor state of road transport infrastructure (metalled roads, vehicles, etc.), traffic control infrastructure (signs, signals, etc.) and vehicle technology (high capacity buses, environmental friendly vehicles, etc.).	*Please state your situation rate here*	*Please state your importance of the situation factor here*
	Moderately Unfavourable	**2**	The disaster area exhibits a very poor state of road transport infrastructure, traffic control infrastructure and vehicle technology.		
	Slightly Unfavourable	**1**	The disaster area exhibits poor road transport infrastructure, traffic control infrastructure and vehicle technology .		
	Favourable	**0**	The disaster area exhibits negligible problems related to technological aspects state above.		
Environmental development state	**Highly Unfavourable**	**3**	The disaster area exhibits an extremely undesirable physiographic, climatic and built-environmental state.	*Please state your situation rate here*	*Please state your importance of the situation factor here*
	Moderately Unfavourable	**2**	The disaster area exhibits a moderately undesirable physiographic, climatic and built-environmental state.		
	Slightly Unfavourable	**1**	The disaster area exhibits a slightly undesirable physiographic, climatic and built-environmental state.		
	Favourable	**0**	The disaster area exhibits a good state of physical, climatic and built-environmental state.		
Economic development state	**Highly Unfavourable**	**3**	The disaster area experiences extreme economic problems due to gross underfunding among Population, State and Nation.	*Please state your situation rate here*	*Please state your importance of the situation factor here*
	Moderately Unfavourable	**2**	The disaster area experiences extensive economic problems due to substantial underfunding among population, State and Nation.		
	Slightly Unfavourable	**1**	The disaster area experiences significant economic problems due underfunding among population, State and Nation.		
	Favourable	**0**	The disaster area does not experience economic problems.		
Political and administrative development state	**Highly Unfavourable**	**3**	The disaster area has very large number of intense problems of political and administrative nature, pertaining to participation, attitudes, stability and enforcement of laws.	*Please state your situation rate here*	*Please state your importance of the situation factor here*
	Moderately Unfavourable	**2**	The disaster area has large number of intense problems pertaining to political and administrative developmental state.		
	Slightly Unfavourable	**1**	The disaster area has samller number of intense problems pertaining to political and administrative developmental state.		
	Favourable	**0**	The disaster area does not experience political and administrative problems.		

Note :1)The situation rating need to be based on scale, intensity and type of disaster impact on transport developmental state.
2)The situation rating may involve either an individual criterion or a combination of different criteria based on data availability.
3)The value of different indicators of situation factors based on certain criteria could be used to rationalise the situation rating.
4)The upper and lower values of indicators could be set according to the disaster characteristics.
5)The situation rating need tobe based on inter-relationships between different situation factors.
6)The situation rating given above is always relative, with higher grades representing the more negative.

Table 9-3: Description of disaster transport situation (Transport Development State)

Interrelationships of transport development state with transport supply and demand condition

The relationship of the transport development state with the transport supply condition and the transport demand condition reveals the following (see Figure 9-7):

- The impact of the social development factors on the transport demand factors has been observed in the study. The population disabilities due to illnesses, illiteracy and other barriers do in fact influence the number of trips, trip purpose, trip duration and trip distance.
- The impact to transport development factors is observed on transport supply condition. The technological development state of transport influences the susceptibility of transport supply to the disaster impacts in the disaster affected or prone region.

Transport development state \ Disaster impact on Transport supply and Transport demand		Transport supply condition			Transport demand condition			
		Impact on roads, terminals and traffic control devices	Impact on vehicles	Impact on transport user and operator	Magnitude of trips	Trip purpose	Trip duration	Trip distance
Social development state	Physical state of population	-	-	O	X	X	X	X
	Educational state of population	-	-	O	X	X	X	X
	Personal state of population	-	-	O	X	X	X	X
Technològical development state	State of transport infrastructure development	X	X	X	O	O	O	O
	State of traffic control technology	X	X	X	O	O	O	O
	State of vehicle technology	X	X	X	O	O	O	O
Environmental development state	Physiographic state	X	X	X	X	X	X	X
	Climatic state	X	X	X	X	X	X	X
	Built-up environmental state	X	X	X	X	X	X	X
Economic development state	Economic state of population	-	-	-	-	-	-	-
	Economic state of State	-	-	-	-	-	-	-
	Economic state of Nation	-	-	-	-	-	-	-
Political and administrative development state	Political and administrative attitudes	-	-	-	X	X	X	X
	Political stability	-	-	-	X	X	X	X
	Enforceability of laws and regulations	-	-	-	X	X	X	X

Legend:
- x Major impact
- o Moderate impact
- - Insignificant or no established impact

Figure 9-7: Interrelationships of transport development state (Disaster Impacts)

- The impact of environmental development factors is observed on transport supply and demand factors. This is mainly due to the lack of accessibility, poor climatic conditions, and

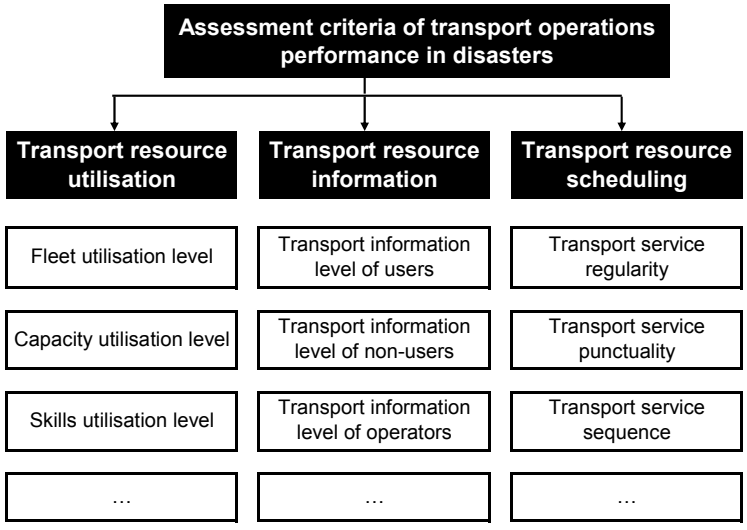
a poor built-up environment which further deteriorates the transport supply and impacts the transport demand by increasing the number of trips, trip purposes, trip duration and the trip distances.

- The impact of political development factors is observed on the transport demand factors. The transport demand is influenced by the political and administrative coordination, ease of development and implementation of new policies and regulations, and proper judicial arrangement.

Assessment of transport operations performance

In most disasters and especially in unpredictable disasters, there will be a great uncertainty about the transport operations performance. Transport resource allocation and scheduling are the most important operation techniques for optimising the scarce transport resources in disasters. However, in an absence of specific objectives and a well-formulated transport policy, transport operations in disasters face problems pertaining to transport resource utilisation, transport resource information and transport resource scheduling resulting in a counterproductive transport system. The reasons to estimate the transport operations performance are as follows (see Figure 9-8):

- To estimate the under-utilisation of resources of transport service, transport capacity and transport user/operators skills for the improvement of traffic management.



Note: The above given transport operations performance indicators are incomplete and indicative only.

Figure 9-8: Criteria to assess transport operation performance

- To estimate the information level of transport user, non-users and operators for the improvement of traffic management.
- To estimate the transport resource scheduling for the improvement of traffic management.

This section addresses the transport operational problems and issues which cause inefficiency of the transport system although the transport resources (transport infrastructure supply) and the traffic management potential exists (fair transport development state). The estimation of transport system operations performance is conducted for urban transport modes such as public transport,

individual motorised transport, service transport and goods transport. The following sections provide the indicators of poor transport operations during disasters:

Transport resource utilisation – The evaluation indicators of transport resource utilisation are based on the three criteria of (i) **fleet utilisation level (vehicle utilisation)**, (ii) **capacity utilisation level (road and urban space utilisation)** and (iii) **skills utilisation level (transport users and operating staff)**.

The criteria of fleet utilisation include utilisation of the public transport fleet and the freight transport fleet; they are measured in person-kilometres, tonnes-kilometres and load factors (tonne km/vehicle km). This is used to indicate the under-utilisation of transport resources that lead to poor transport operations.

The criteria of capacity utilisation include all network components such as roads, lanes, bridges, culverts, terminals, etc. in order to measure the highway capacity, they are measured in daily vehicle kilometres travelled per lane and a ratio of volume to service flow among others.

The criteria of skills utilisation include use of skills of transport users and operators; and they are measured in total staff per licensed vehicle, manpower deployed per activity among others.

It is important to consider the transport resource utilisation as it affects the utilisation of severely deficient transport resources during disasters. Thus, it is necessary to control the vehicle occupancies and the allocation of manpower resources (skilled and unskilled) for the success of traffic management.

Transport resource information – The evaluation indicators of transport resource information are based on the three criteria of (i) **transport information level of users,** (ii) **transport information level of non-users**, and (ii) **transport information level of operators**.

The criteria of information level of transport users include all types of traffic and disaster-related information provided to change the travel behaviour and they are measured in % user satisfaction with transport information and % of informed transport users, etc.

The criteria of information level of non-transport users include an assortment of information provided to change the travel behaviour of potential transport users, measured in % reduction of total traffic with transport information, % of shift in peak hour traffic, etc.

The criteria of information level of transport operators include a variety of information sharing and other participation efforts among different transport operators to optimise the transport system efficiency, measured in % of linked trips, % of reduction in total trips through stakeholder's participation, etc.

There are many different uses of traffic information to users, non-users and operators depending on the expected output of information. It is important to consider the information level of various groups as it affects the optimal utilisation of resources through more effective public awareness, training and participation. Therefore, it is necessary to devise methods and procedures for both traffic information collection and for dissemination to enhance effectiveness of traffic management.

Transport resource scheduling – The evaluation indicators of transport resource scheduling are based on the three criteria of (i) **transport service regularity**, (ii) **transport service punctuality** and (iii) **transport service sequence**.

The criteria of transport service regularity include service continuity and frequency at the time of disaster and they measured in time of operation of transport service in hours, days or months and number of operations per hour (service frequency).

The criteria of transport service punctuality include promptness of transport service operations and they are measured in % of arrival delays (min or hours) and % of departure delays (minutes or hours), etc.

The criteria of transport service sequence involve coordination among several transport modes such as public transport, individual transport, service transport and goods transport to effectively utilise the road space and to improve traffic flow conditions for quick disaster response and recovery. Transport service sequence fulfils the demand for priority of different transport modes and transport users depending on the disaster situation. The sequencing of disaster management activities before, during or after disaster is beyond the domain of traffic management; although, a thorough understanding of DM processes is required to support the given order of disaster management activities in space and/or time.

The sequence of activities is based on priority, and can be set between the same transport modes or between different transport modes. The sequence of activities of disaster management mostly involves multiple modes. The criteria of transport service sequence with respect to traffic management includes priority given to the various transport modes (such as high capacity buses) and people with the greatest needs (people requiring medical support, people living in most vulnerable locations, etc.). The indicators describing the criteria depend on the type of transport modes. The public transport sequence indicators are the number or percentage of connections per public transit route/operation time, transfer time in minutes, etc. The sequencing of public transit is often used to ensure the vehicle occupancies. The individual transport sequence can be described through the signal timings and can be measured in percentage of the network employing green wave coordination. The service and goods transport can be described through percentage of items delivered in a given time span (hours, days or week) and the time taken for items delivered (donation-to-delivery time) among other indicators. The other indicators of transport service sequence involving multiple modes could also be described by delay reduction when time segregation between conflicting modes is enforced.

The above indicators of transport service scheduling indicate the resource utilisation which exploits the synergy effects of multimodal coordination. The principles of time segregation are used to optimise the deficient resources through a procedural plan sequence (time differential) of each transport operation involved in disaster management.

Situation Factors	Level of Situation	Grades	Situation Description	Situation Rating	Relative Weight
Transport resource utilisation	**High Under-utilisation**	**3**	The situation depicts the extensive under-utilisation of public and freight transport fleet, road capacity, and/or transport user and operators skills.	*Please state your situation rate here*	*Please state your importance of the situation factor here*
	Moderate Under-utilisation	**2**	The situation depicts the moderate extent of under-utilisation of public and freight transport fleet, road capacity, and/or transport user and operators skills.		
	Slight Under-utilisation	**1**	The situation depicts relatively fewer incidences of under-utilisation of public and freight transport fleet, road capacity, and/or transport user and operators skills.		
	Adequate Utilisation	**0**	The situation depicts adequate utilisation of transport resources.		
Transport resource information	**Highly Uninformed**	**3**	The situation depicts a very large number of uninformed transport user, transport non-user and/or transport operator groups.	*Please state your situation rate here*	*Please state your importance of the situation factor here*
	Moderately Uninformed	**2**	The situation depicts a large number of uninformed transport user, transport non-user and/or transport operator groups.		
	Slightly Uninformed	**1**	The situation depicts considerable number of uninformed cases among transport user, transport non-user and/or transport operator groups.		
	Informed	**0**	The situation depicts adequate information levels among the transport user, transport non-user and transport operator groups.		
Transport resource scheduling	**Highly Unscheduled**	**3**	The situation depicts very poor transport resource scheduling due to poor regularity, punctuality and/or sequence of transport services.	*Please state your situation rate here*	*Please state your importance of the situation factor here*
	Moderately Unscheduled	**2**	The situation depicts poor transport resource scheduling due to inadequate regularity, punctuality and/or sequence of transport services.		
	Slightly Unscheduled	**1**	The situation depicts only some minor discrepancies in transport resource scheduling due to inadequate regularity, punctuality and/or sequence of transport services.		
	Scheduled	**0**	The situation depicts adequate scheduling of transport services.		

Note:1)The situation rating should be based on scale, intensity and type of disaster impact on transport operations performance.
2)The situation rating may involve either an individual criterion or a combination of different criteria based on data availability.
3)The value of different indicators of situation factors based on certain criteria could be used to rationalise the situation rating.
4)The upper and lower values of indicators could be set according to the disaster characteristics.
5)The situation rating should be based on inter-relationships between different situation factors.
6)The situation rating given above is always relative, with higher grades representing more negative.

Table 9-4: Description of disaster transport situation (Transport Operational Performance)

The transport indicators are values, standards or metrics in order to evaluate the formulated strategies and the transport situations. The transport indicators in the disaster impacted area could be used to express the previous, existing or potential state of the transport system. The selection and the applicability of transport strategies are based on the estimation of the transport situation. The transport situation can be evaluated qualitatively or quantitatively depending on the availability of data and effort required. The scenario analysis is used to estimate the impacts of formulated transport strategies for a particular or hypothetical transport situation. Therefore, it is important to choose the right indicators to reflect the transport situation. The evaluation of indicators often involves the comprehensive collection of data, which might be difficult to collect during the time of operations. The evaluation indicators described in earlier sections are just indicative and provide a framework for the preliminary analysis of the transport situation.

Interrelationships of transport development state with transport operations performance

The relationships of transport development state with the transport operations performance reveals the following (see Figure 9-9 and Figure 9-10):

- The impact of the social development factors on transport resource information is observable. The population disabilities due to illnesses, illiteracy and other barriers do substantially affect the skills utilisation and the transport information level among users, non-users and operators.
- The impact of transport developmental factors on all factors of transport operations performance is observable. This relationship is effective mainly due to the pre-requisite of good technological development for transport operations performance.

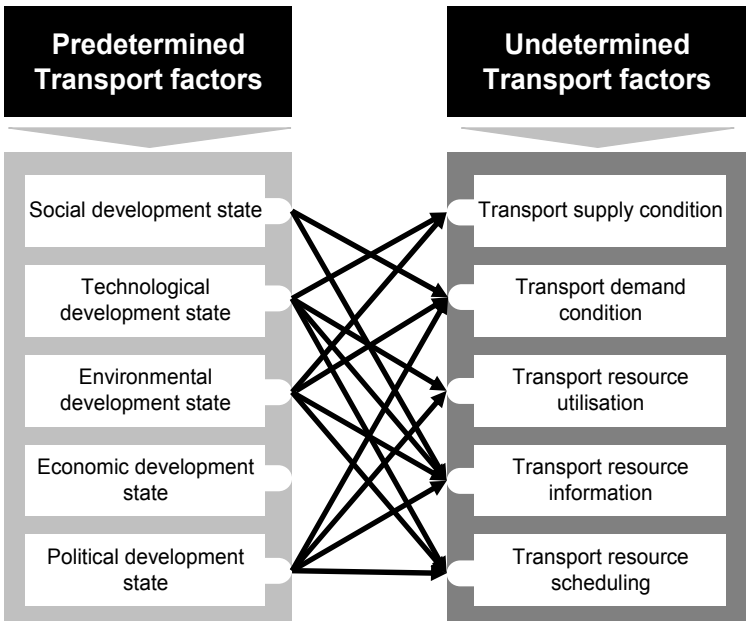


Figure 9-9: Interrelationships of predetermined and undetermined transport factors

- The impact of the environmental development factors is mainly observable as it impact on the information level of users, non-users and operators due to lack of accessibility, lack of information dissemination methods and people with differential information needs. It also affects the regularity, punctuality and sequencing of disaster transport operations.
- The economic state of people, State or Nation partially impact on almost all transport operation performance factors due to availability of economic resources for improvising performance. However, the subject of transport operation performance is considered as a quality indicator of traffic management and needs to be implemented even in a deficient economic developmental state of the disaster-affected or disaster-prone area.
- The impact of political developmental state is observed on all key factors of transport operation performance. The impacts are due to prerequisites of political and administrative coordination, ease of development and implementation of new policies and regulations, and proper judicial arrangement for the transport operations performance.

Transport development state		Transport resource utilisation			Transport resource information			Transport resource scheduling		
	Transport operations performance	Fleet utilisation level	Capacity utilisation level	Skills utilisation level	Transport information level of users	Transport information level of non-users	Transport information level of operators	Transport service regularity	Transport service punctuality	Transport service sequence
Social development state	Physical state of population	-	-	X	X	X	X	-	-	-
	Educational state of population	-	-	X	X	X	X	-	-	-
	Personal state of population	-	-	X	X	X	X	-	-	-
Technolgical development state	State of transport infrastructure development	X	X	X	X	X	X	X	X	X
	State of traffic control technology	X	X	X	X	X	X	X	X	X
	State of vehicle technology	X	X	X	X	X	X	X	X	X
Environmental development state	Physiographic state	O	O	O	X	X	X	X	X	X
	Climatic state	O	O	O	X	X	X	X	X	X
	Built environment state	O	O	O	X	X	X	X	X	X
Economic development state	Economic state of population	O	O	O	O	O	O	-	-	-
	Economic state of State	O	O	O	O	O	O	O	O	O
	Economic state of Nation	O	O	O	O	O	O	O	O	O
Political and administrative development state	Political and administrative attitudes	X	X	X	X	X	X	X	X	X
	Political stability	X	X	X	X	X	X	X	X	X
	Enforceability of laws and regulations	X	X	X	X	X	X	X	X	X

Legend:
- **x** Major impact
- **o** Moderate impact
- **-** Insignificant or no established impact

Figure 9-10: Interrelationships of transport development state (Transport Operations Performance)

Disaster transport situation assessment model

The disaster transport situation assessment model involves the following steps:

- Selection of the most relevant factors required for the disaster situation assessment.
- Obtain the relative weights of importance of all situation factors relevant to traffic management for a disaster.
- Obtain the situation rating of all situation factors.
- Calculate the cumulative score for a particular disaster situation (summation of all the multiplication results of situation rating and their corresponding relative weights of importance).

- Check the cumulative score for their qualification in **SL** (**A)** to **SL** (**E)**.

The rating scale concept is used for the qualitative assessment of disaster transport situation. The survey design in this study is based on theoretical as well as quantitative data supporting the psychological measurement. The initial stage of this method involves the identification of situation factors and/or parameters which reflect the important aspects of disaster transport situation and pose challenges to disaster traffic management. After the identification and pre-selection of situation assessment modules and situation assessment factors, the criteria for the evaluation of situation factors are identified. The criteria of evaluation of each situation factor provide the situation rating based on qualitative and quantitative assessments. Based on the literature review and pilot study of the tsunami affected area in Nagapattinam, Tamil Nadu, India, ten parameters were identified and included in the disaster transport situation assessment. Two situation factors pertaining to the disaster impacts on transport demand and supply were included; these are the transport supply condition and the transport demand condition during disaster. The five situation factors pertaining to the transport development state of the disaster area are included; these are the social, technological, environmental, economic and political/administrative state of the disaster affected area. The three situation factors pertaining to the transport operation performance are included, and these are transport resource utilisation, transport resource information and transport resource scheduling.

The two important evaluations (i) **relative weights of importance of each situation factor** and (ii) **situation rating with respect to each situation factor** were conducted in order to provide the final level of situation. The importance of each situation factor in the transport situation is described by the different weights provided by various groups of people and are considered constant for the purposes of this study. Moreover, the relative importance of each factor depends on both (i) **individual perception about the importance** and (ii) **the disaster characteristics in the local environment**.

The responders were asked to assign weights to all ten situation factors according to their perception of importance about the factor. The importance of situation factors were rated on a scale of 1 to 5 with 5 representing the most important and 1 the least important situation factors. The average is taken to obtain the final relative weights and is fixed for the analysis. A total of twenty interviews were conducted by direct interview method to obtain the relative weights and situation rating. The data was gathered on the situation rating of each factor as experienced by the respondent during the disaster. A scale of 0 to 3, 3 representing the worst situation and 0 representing the ideal or no impact situation has been used. The situation descriptions and their corresponding grades of rating are explained in Table 9-2, Table 9-3, and Table 9-4. The implicit assumption is made that the responder is able to relate his opinion about the situation rating and relative weights (corresponding importance) into a number. In addition, it is assumed that if variability occurs among the ratings of a given situation factor across a group of people, this variability reflects disagreements about the status of object but doesn't relate to the disagreements about the boundaries of intervals into which situation factors may fall.

The weights assigned to the importance and the satisfaction was used to develop qualitative **situation level (SL) model** for the disaster cases of study. The developed qualitative level of service is based on the extensive primary surveys and a self onsite assessment of the disaster affected area. Furthermore, the data of hypothetical disasters of similar nature has been used for the estimation of attitudinal scores.

The calculation of total weighted scores for similar disaster situations (hypothetical transport situations) is carried out to define the five levels of situation in disasters; for example SL (A) to SL (E). SL (A) indicates a worst level of situation and SL (E) indicates a fair level of situation with respect to traffic management.

Catastrophic SL (A)	Permanent or partial damage of equipments or systems (transport supply system) to accomplish the disaster management functions. Prevalance of very high traffic demand and associated problems. The existing transport development state is very poor. Worse transport operations performance due to very high under-utilisation, very large uninformed transport users and operators, and very poor transport resource scheduling.
Critical SL (B)	Significantly degraded transport supply to accomplish the disaster management functions. Prevalance of high traffic demand and associated problems.Transport development state is generally poor due to single or multiple contributing factors of social development, technological development, environmental development, economic development and political development. Transport operations performance critical to traffic management.
Marginal SL (C)	Degraded transport supply capacity or partial damage to critical traffic management equipments or systems to accomplish the disaster management functions. Temporary or permanent increase of traffic demand and associated problems.Transport development state is unfavourable for the traffic management. Transport operations performance marginal to traffic management.
Near Negligible SL (D)	Minor damage to equipments or system damage but servicable to accomplish the disaster management functions. Slight increase in traffic demand and time-limited associated problems.Transport development state is slightly unfavourable for the traffic management. Transport operations performance is slightly unfavourable to traffic management.
Negligible SL (E)	Little or no adverse impact on traffic management equipments or systems to accomplish the disaster management functions. Transport supply adequate to cater the slight increase of traffic demand. Transport development state is favourable for the current traffic managment. Transport operations performance is according to the traffic management requirements.

Situation level (SL) rating descriptions

The hypothetical situation ratings have been used to obtain the weighted scores. Finally, the mean and standard deviation are used to define the upper limit of the cumulative score, lower limit of the cumulative score and the range of different levels of situations. If the standard variation is small, it indicates that the data values are clustered closely around the mean. In this case one complete interval of standard variation is not required to set the upper limit, lower limit and interval. In cases where the standard deviation is larger, then the mean plus one standard deviation is used to define the upper limit and any score above that would qualify a situation to be worst in nature SL (A). The lower limit minus two standard deviations is used to define a fair situation and any cumulative score less than would qualify for SL (E). The interval of one standard deviation could be used to define the ranges for SL (B), SL (C) and SL (D) situations. It is desirable that disaster cases which qualify for SL (A), SL (B), and half of SL (C) should fall within 50 to 60 percent in order to indicate the problem level in various groups. It is also desirable that SL (D) and SL (E) cases would not exceed 30% in any circumstance. The intervals for the cumulative scores could be marginally modified to satisfy the above criteria (see Table 9-5).

Situation Level	Cumulative Score	Expected %
SL (A)	>75	60-70 %
SL (B)	65-75	
SL (C)	55-65	
SL (D)	45-55	30-40 %
SL (E)	<45	

Note : Mean = 66, Standard deviation =12

Table 9-5: Grading scheme of situation level SL (A) to SL (E)

Summary of transport situation assessment for tsunami affected areas of Nagapattinam

The onsite assessment was carried out in the municipal area of Nagapattinam town of Tamil Nadu, India, to present the level of situation. Qualitative level of situation model is applied to estimate the level of situation to aid in the decision making about type, selection and implementation of strategies. This section deals with the estimation of level of situation based on the situation rating of situation factors for the tsunami disaster.

The situation in Nagapattinam disaster area has a cumulative score of 76, which qualifies for the SL (A) disaster (see Table 9-6).

Transport situation during disaster can be described through the combination of several factors. The several factors responsible can be grouped into modules to present the challenges to the traffic management. The three modules are considered in order to describe the transport situation; for example disaster impacts on transport supply and the generation of transport demand, prevailing transport development state of the disaster prone or affected area, and the performance of the transport system in disasters. It is a difficult task to assign the individual transport problem to any single module since, an individual transport related problem in disaster is due to a combination of various factors of one or more modules.

In order to form the scenario it is necessary to segregate the uncertain factors from the certain factors of transport situation. The uncertain modules of transport situation are disaster impacts on transport supply and the generation of transport demand and the performance of the transport system.

Transport situation in disasters can be assessed precisely based on the three main criteria of disaster impacts on transport supply and demand, prevailing transport developmental state and finally the transport operations performance.

The disaster impacts on the transport supply are mostly unknown due to varying intensity, scale and magnitude of a disaster. The transport development state cannot assess precisely the effect of poor transport developmental state on transport supply and demand as it indicates the likelihood of probable impact only. An excellent transport development state can result as a high impact on transport supply and generate a high transport demand. Transport supply includes roads, terminals, traffic control devices, vehicles and the transport users. The transport demand consists of all trips which are generated due to the disaster management functions activated after or before the occurrence of a disaster and trips which are non-disaster related are also included in the total transport demand.

Thus, the vulnerability assessment needs to indicate the nature, intensity, scale and magnitude of loss incurred on the transport infrastructure. It needs to also highlight the total transport demand generation before and after the disaster.

The assessment of transport development state is necessary to provide the effectiveness and the applicability of the available transport measures. The evaluation of transport development state will provide indication about the applicability of traffic management measures available to the transport operators and managers. The evaluation will also highlight the need for the improvement of certain aspects of the transport developmental state in order to improve the efficacy of the formulated transport strategies.

Situation Factor	Salient disaster features	Situation Rating	Relative Weight
Transport supply condition	The tsunami waves caused a substantial damage to roads, terminals, traffic control devices and vehicles.	**2**	**4,5**
Transport demand condition	A very large number of trips generated with large variations of O/D and trip duration.	**3**	**4,25**
Social development state	The disaster area exhibits a less but still considerable population with physical illnesses, illiteracy and personal disabilities due to age, gender, language, religion, etc.	**2**	**2,5**
Technolgical development state	The disaster area exhibits a very poor state with problems of road transport infrastructure, traffic control infrastructure and vehicle technology.	**2**	**3,75**
Environmental development state	The disaster area exhibits a slightly undesirable physiographic, climatic and built-environment state.	**2**	**2,75**
Economic development state	The disaster area experiences significant economic problems due underfunding among population, State and Nation.	**2**	**3**
Political and administrative development state	The disaster area has large number of intense problems pertaining to political and administrative developmental state.	**2**	**3,25**
Transport resource utilisation	The situation depicts the extensive under-utilisation of public and freight transport fleet, road capacity, and/or transport users and operators skills.	**3**	**4,25**
Transport resource information	The situation depicts a large number of uninformed people among transport user, transport non-user and/or transport operator groups.	**2**	**2,5**
Transport resource scheduling	The situation depicts poor transport resource scheduling due to inadequate regularity, punctuality and/or sequence of transport services.	**2**	**3**

Note : Cumulative score = 76
Situation Level = A

Table 9-6: Summary of transport situation assessment (Case Study-Nagapattinam)

Traffic management scenario development and assessment

The traffic management scenarios are the combination of relatively unknown transport situations (due to transport problems, transport development state, and transport operation performance) and the relatively known traffic management measures (or strategies). Thus, in the formation of the traffic management scenario, it is necessary to assess transport situation and traffic management strategies as accurately as possible. Table 9-7 provides four traffic management scenarios based on 3 levels of TM strategies and 5 transport situation levels.

Traffic Management Strategies		Transport Situation				
		SL (A)	SL (B)	SL (C)	SL (D)	SL (E)
		Catastrophic	Critical	Marginal	Near Negligible	Negligible
Worst Strategies	I	E	E	H	H	M
Poor Strategies	II	E	M	M	L	L
Reasonable Strategies	III	M	L	L	L	L

where E: Extremely High Risk Scenario, H: High Risk Scenario, M: Moderate Risk Scenario, L: Low Risk Scenario

Table 9-7: Traffic management scenario assessment matrix

The effective traffic management strategies are required to decrease the extremely high risk scenario to low risk scenario.

Decision making support

Commonly required traffic management strategies

Traffic managers constantly seek decision making support on the type of disaster traffic management strategies for various disaster transport situations. The knowledge of commonly required traffic management strategies is also important for traffic managers. This knowledge of commonly required and applicable TM strategies provides traffic managers with the requirements of TM systems and TM modules. Based on the descriptions of transport situations, the required and applicable TM strategies are deduced. Of the five traffic demand reduction strategies, **strategy to increase the vehicle utilisation of transport modes** and **strategy to improve the spatial distribution of traffic volume** are commonly required demand reduction strategies. Of the four transport supply augmentation strategies, **strategy to improve the transport supply capacity** and **strategy to reduce the disturbances of traffic flow** are most commonly required supply augmentation strategies.

Commonly required traffic management measures

Based on the commonly required and applicable traffic management strategies, the common measures that form the strategies are selected (Table 9-8).

Inapplicable traffic management measures

Based on the prior assessment of 27 pre-selected TM measures, it is found that the TM measures such as **Road Network Control**, **Road Section Control** and **Traffic and Disaster Information Service** are commonly required TM measures for most traffic management strategies but these measures pose difficulties of application due to high costs of implementation, high use of advanced technical systems, high requirements of stakeholder's participation and public acceptance.

Applicability improvement methods

The applicability of TM measures depends on the difficulty factors. These difficulty factors are related to four areas of transport sector which are: (i) transport economics, (ii) traffic technology, (iii) transport politics, and (iv) traffic education. Inefficient and undeveloped transport sector areas pose several vulnerabilities to the traffic management system in cases of disasters. However, this

study considers that the applicability improvement methods, procedures or techniques will be existent and applied to reduce the difficulties of implementation of TM measures in the disaster-affected or disaster-prone region. The following sections will provide the methods available to traffic managers to reduce the difficulties of implementation of TM measures.

Transport Economics

• Use indigenous infrastructure, technology and manpower,

• Improve the utilisation capacity of existing transport supply (infrastructure and manpower),

S.No.	Traffic Management Measures	Measure Category	Strategy to increase the vehicle utilisation of transport modes	Strategy to improve the spatial distribution of traffic volume	Strategy to improve the transport supply capacity	Strategy to reduce the disturbances of traffic flow
PT	Public Transport Measures					
1	Public Transport Network Improvement	T-O	◑	●	◑	○
2	Public Transport Scheduling Improvement	T-O	●	●	◑	○
3	Public Transport Accessibility Improvement	T-O/INFR	◑	●	●	○
4	Public Transport Capacity Improvement	T-O/INFR	●	◑	●	○
5	Special Disaster Transport Services	T-O/ADMN	○	○	●	○
6	Public Transport Right-of-Way Prioritisation	T-O	◑	○	◑	◑
7	Public Transport Information Services	INFO	◑	◑	◑	◑
8	Public Transport Management Centre	T-O/INFO	◑	◑	◑	◑
NMT	Non-Motorised Transport Measures					
1	Establishment of Pedestrian routes & Facilities	T-O/ADMN	○	○	◑	○
2	Establishment of Bicycle routes & Facilities	T-O/ADMN	○	○	◑	○
IMT	Individual Motorised Vehicle Measures					
1	Carpooling & other Ride Sharing Programs	ADMN	●	○	●	○
2	Car Rental Services	ADMN	●	○	●	○
3	Automobile Roadway Repair Service	ADMN	○	○	◑	○
4	Special Traffic Rules Enforcement	ADMN	○	◑	○	●
MIM	Multimodal and Intermodal Transport Measures					
1	Economic or Preferential Incentives	T-O/ECO	●	●	●	○
2	Trip reduction & Land-use Modification Ordinances	ADMN	●	●	●	○
3	Road Network Control	T-O	○	●	●	●
4	Road Section Control	T-O	○	●	●	●
5	Improvement of Signalised Traffic Control	T-O	○	●	●	●
6	Improvement of Non-signalised Traffic Control	T-O	○	●	●	●
7	Improvement of Inter-modal and Parking Facilities	T-O/ADMN	●	◑	●	○
8	Traffic & Disaster Information Service	T-O/INFO	●	●	●	●
9	Disaster Traffic Management Centre	T-O/INFO	◑	◑	◑	●
10	Work- Zone Coordination & Management Centre	T-O/INFO	◑	◑	◑	●
FR	Freight Transport Measures					
1	City Logistics System	T-O/ADMN	●	○	●	◑
2	Household Goods Delivery Transport System	T-O/ADMN	●	○	◑	◑
3	Freight Traffic Operations Control	T-O/ADMN	○	●	◑	●

Note:

Fully applicable measures	●
Partially applicable measures	◑
Less applicable measures	○

Table 9-8: Common traffic management measures

• Follow existing organisational framework,

• Involve private sector and non-profit organisations in implementation of measures,

• Alternative modes of application of measures (non cost-intensive),

• Effective planning and law-enforcement for quicker response and reduction of application time of TM measures, etc.

Traffic Technology

• Select alternative traffic and transport systems (traditional traffic systems and technology),

• Select non-resource intensive measures,

• Identify traditional methods of traffic control such as manual traffic control,

• Harness potential of infrastructure sharing, such as military infrastructure, traffic and transport infrastructure of neighbouring states, etc,

• Select measures that can use existing transport infrastructure through effective coordination, etc.

Transport Politics

• Selection of experienced and responsible representatives of transport politics,

• Improve decision-making of States, organisations and people towards independent decision-making during disasters,

• Adequately address TM problems to potential stakeholders,

• Limit the amount and scale of decision-making authorities,

• Minimise concurrence in operation of transport services,

• Build effective relationships between transport stakeholders,

• Strict monitoring and control of transport operations, etc.

Traffic Education

• Improve awareness of transport users,

• Adequately address TM problems and justification of benefits of TM measures,

• Improve law enforcement,

• Propose equivalent benefits to the affected transport users, compensation packages to transport operators, etc,

• Involve non-transport users in process of traffic management, etc,

• Increase the time-of-resilience (time to adjust to new conditions) in cases of affected groups.

9.4 Summary

Application of scenario planning process for qualitative assessment of traffic management scenario is explained in this chapter. The assessment of TM scenario is dependent on the relatively undetermined transport situation and determined traffic management strategies in the local environment. The assessment of TM strategies is based on effectiveness and difficulties-of-implementation of TM measures explained in Chapter 7. However, an assessment of transport situation involved a comprehensive identification and development of assessment modules, factors, criteria and indicators of assessment. The interrelationships between the transport situation factors are also discussed. Situation levels based on the assessment of transport situations are evolved and described. A qualitative disaster transport situation assessment model

is developed to assess and validate the situation level for a case study area, Nagapattinam, Tamil Nadu, India for a tsunami disaster occurred in 2004. The summary of assessment results indicated the worst transport situation level SL (A) for the tsunami disaster. Based on three levels of TM strategies and five levels of transport situations, four hypothetical TM scenarios are created to provide the decision making support on the identification of most commonly required TM strategies and measures. Furthermore, based on prior knowledge of inapplicable TM measures and their utmost requirement for the development of TM strategies in disasters, the applicability improvement methods are discussed into four areas of transport viz. transport economics, traffic technology, transport politics and traffic education. Thus, this chapter provided a comprehensive framework of TM scenario development and its support for decision making on traffic management in disasters.

10 Proposals

10.1 Introduction

The data and analysis given in the previous chapters confirms the need of proposal for strategies application in a case study city. The capital city of India, New Delhi is selected as a case study city. This chapter illustrates the application of strategies in New Delhi by introducing suitable modification in the available TM mechanisms and processes which are referred as TM modules in this study. The twelve previously identified TM modules provide the orientation of proposals for strategies application. The data on traffic and transport in Delhi is presented in the Annexure J.

10.2 Proposals for Traffic Management Modules in Delhi

The main proposals are grouped in traffic management modules given below:

- **Political and Administrative Framework**

1. The establishment of additional traffic and transport departments within the political and administrative framework of traffic management in Delhi are proposed to reduce high dependence on Delhi Traffic Police (DTP). These departments should be trained to work with other disaster management organisations under any command system.
2. The involvement of volunteer groups, private sector and non-profit organisations is proposed to improve the design and manufacturing of traffic control devices, and in the application of manual traffic control. Agreements, pacts and joint ventures related to institutional participation and public acceptance need to be addressed within the political and administrative framework of Delhi in anticipation of disasters.
3. Inter-state bus operation agreements are proposed as prerequisites of effective measures for capacity building on infrastructure sharing basis (vehicles, staff and traffic control devices) in all parts of National Capital Region of Delhi (NCR). Effective relationships and agreements are required between Delhi Transport Corporations and neighbouring States Transport Corporations (e.g. UPSRTC, HRTC, etc.).
4. Taxi operation agreements are proposed to introduce personalised para-transit services for mobility-disable groups (e.g. old people, sick people, etc.).
5. Transport law authorities including Delhi Traffic Police need to develop special traffic rules implementable in disasters in accordance with Delhi Disaster Management Act, 2004, Motor Vehicles Act, 1989, Central Motor Vehicle Rules, 1989, Delhi Motor Vehicle Rules, 1989 and Rules of Road Regulation, 1989. The development of traffic rules during disasters should include the establishment of triage system, vehicle improvement rules, speed limits, parking and overtaking restrictions, etc.
6. Economic and preferential incentives for public transport are proposed to encourage its use. This should include free transport in disasters to low income people or bus operations in low-income areas. The administrative agencies (e.g. revenue departments) also need to provide subsides to public transport operators during disasters. The subsidised operations should be applicable to DTC buses, Delhi Metro, Auto- rickshaws, Taxis and other suitable public transport modes.

- **Land-Use Zoning Regulations**

7. The proposals comprise of permanent and temporary zoning of the land use of Delhi. This study supports the regularisation of unauthorised colonies of Delhi and hence land-

use changes. However this study opposes the proposed mixed land-uses indicated in the new regulations, directives and Delhi Master Plan, 2021 due to compounding impact on traffic management. Deputy Commissioner of DDMA need to be given additional powers to take temporary possession of schools, stadiums, playgrounds, public and private properties to use for transport and traffic management activities. Furthermore, the closure and opening arrangements (hours and days of operation) of public and private establishments (schools, offices, etc.) are proposed for trip reduction purposes.

8. The development of traffic management guidelines by DDMA for various land-uses and traffic zones in Delhi is proposed. These guidelines must be mandatory to follow by land development authorities (DDA, MCD and private developers) for fulfilling traffic management requirements (e.g. space for parking provisions, traffic calming regulations, speed limits in residential areas, etc.). This endeavour will integrate developmental planning into disaster management including traffic management on a long-term basis.
9. The implementation trip reduction ordinances to promote the alternate time schedules, tele-working, avoid dispensable traffic (disaster tourists, research groups or media) are proposed. Traffic management enforcement agencies such as Delhi Traffic Police, Home Guards, Civil Defence and Delhi Fire Service authorities should be given powers for evacuation and quarantine operations.

- **Capacity Utilisation of Transport Modes**

10. In public transport, the proposal is to operate the high-capacity buses such as double-decker buses. The complimentary measures to support this proposal need to be developed, e.g. Bus Rapid Transit (BRT) routes. Thus, this study supports the development of proposed BRT corridors in DMP, 2021 despite some opposition of IMT users. However in cases of disasters, special bus lanes or routes must be provided.
11. In individual motorised transport, the proposal is to develop car-sharing, car-pooling and other ride-sharing schemes to reduce single occupancies vehicles (SOV). However, safety and security concerns of using this transport should be considered prior to its implementation. These schemes require development of car-pooling and car sharing stations. These stations should be controlled and monitored by DTP by monitoring costs, vehicle conditions and driver's as well as user's registration. Travel data of carpooling customers including name, age, occupation, address, origin and destination of trip, etc. are required for ensuring safety of carpooling customers.
12. Low cost Car-Rental Services are proposed. There is a need to organise the Car-Rental Services to allow favourable competition to reduce the car rentals in Delhi. In addition, State Transport Corporations of Delhi (e.g. Delhi Tourism and Transportation Development Corporation) need to provide such services.
13. To promote the use of multi-modal and inter-modal transport, the proposal is to improve the vehicle design to support the interoperability of vehicles especially public transport (Delhi Metro, DTC buses, etc.) to freight transport and vice versa.

- **Road Pricing and Taxes**

14. Taxes are proposed on disaster tourists, unorganised media companies and unorganised research groups for trip reduction purposes in disaster-affected or disaster-prone areas of Delhi.

- **Traffic Education and Public Awareness**

15. In pre-disaster cases, the terms and conditions of using transport properties and services need to be explained to transport users and operators. DTP should organise special traffic management training exercises to impart education and training to its personnel as well as to transport users. In post-disaster cases, regular updates on traffic and weather information are proposed.
16. A mandatory special course of disaster traffic management is proposed for inclusion in driver's education and training conducted at driving schools. This should include vehicle improvement training, knowledge of special disaster traffic rules, driving behaviour during disasters, etc. The driving skills of potential driver's should be checked prior to issue of driving licences.

- **Traffic and Disaster Information Management**

17. Operation of numerous traffic information booths by Delhi Traffic Police is proposed. Traffic and disaster information services should be provided to current and potential road users during disasters.
18. Traffic Control Cell of DTP should provide the relevant traffic data dynamically to various radio and TV channels for quick dissemination of information to the road users. The traffic and disaster related information should be relayed on radio and TV channels which must include the location of event (incidents/congestion/disasters), time of event, consequence of event and proposal for traffic-related detours. Several weather and traffic monitoring stations are proposed for such information needs. The establishment of dedicated radio channels for the dissemination of traffic information is proposed.
19. The operation of Disaster Traffic Management Centre at or near the disaster-affected or prone regions of Delhi is proposed to coordinate with other sub-centres or information booths for providing traffic and disaster related information service.

- **Inter-Urban and Urban Traffic Control**

The main proposal is the development of traffic management systems such as traffic control and traffic information systems. The Delhi Traffic Police need to develop the following:

20. Formulation and implementation of guidelines for access restrictions and diversion route plans for various disasters types are proposed.
21. Development of speed regulation zones is proposed.
22. Provision of traffic signal pre-emption system at intersections to disaster vehicles, public transport and high occupancy vehicles (HOV). The priority is required for improving traffic conditions and minimising the response and recovery time of disaster vehicles.
23. Application of green-wave principles of traffic signal coordination must be applied to ensure the integration of all upstream signals on desired corridors. Furthermore, back-up power arrangements of all important signals should be developed.
24. Extensive use of traffic control devices including static and dynamic signs, signals and markings for the purposes of traffic control and traffic information dissemination is proposed. In addition, non-signalised traffic control is proposed which uses barricades, traffic cones, dividers, speed breakers, reflective devices, etc. These proposals require extensive upgradation of existing TM infrastructure. However, manual traffic control should be promoted to ensure the adequate employability of traffic personnel.

- **Non-Motorised Transport Improvement**

25. The improvements in the walking environment by effective maintenance of footpaths, providing adequate footpath width, removing encroachments, improving continuity and avoiding potential vehicle conflicts are proposed. The responsible organisations for road development (MCD, PWD, NDMC etc.) should ensure the effective operations of pedestrian lanes. Furthermore, there is a need to consider NMT as a part of transport system of Delhi both in transport planning and development.
26. In general, this study supports and proposes the development of segregated bicycle lanes proposed for more than 500 km of arterial roads (ROW > 45 m) in the Delhi Master Plan (DMP), 2021. The DMP plan proposes three phased development of bicycle lanes, the first phase consists of development of 90 km routes which experience heavy bicycle traffic, the second phase includes 276 km on major arterials and third phased includes 370 km of 30 m ROW roads.
27. In disasters, this study proposes demarcation of road space, safe crossing facilities (through traffic signals or manual traffic control) and the provision of bicycle shelters for bicyclists in order to promote bicycle use for short to medium distance trips (3-5 km).

- **Public Transport Improvement**

28. In general, the development of dedicated Bus Rapid Transit (BRT) corridors is proposed for the public transport network improvement. In disasters, bus priority lanes are proposed whose operation should consider the origin and destination of trips during disasters. DTC and other public transport operators (e.g. Blue line buses) should plan disaster routes by either extending existing routes or providing completely new routes of bus operations. This proposal includes the changes in the location of bus stops, stations and terminals.
29. Feeder bus services to the main public transport stops, stations and terminals are proposed. Extra fleet of feeder bus services should be operational to connect the inaccessible areas of Delhi.
30. The operation of high-capacity buses (HCBS) is proposed. This includes the operation of double-decker buses.
31. Public transport Right-of-Way (ROW) prioritisation is proposed on important roads and on signalised intersections and non-signalised intersections.
32. Connection matching between DTC and other public transport buses is proposed for optimal utilisation of public transport capacities using the similar principles of ITF in Germany to ensure punctuality, frequency, regularity and connectivity.
33. Development and operation of public transport information booths operated by DTC are proposed at disaster-affected or prone areas of Delhi to provide both static passenger information (maps, routes, costs, etc.) and dynamic passenger information (arrival and departure time of buses , next stops and stations, alighting and boarding doors, new routes, on-board passenger information, etc.).
34. Establishment of Public Transport Management Centre during disaster is proposed which should have a central control room, accident cell and a central complaint cell.

- **Freight Transport Improvement**

Freight transport improvements are proposed by the application of City Logistics System, Household Goods Delivery System and Freight Traffic Operations Control.

S.No	Traffic Management Measures	Measure Category	Strategy to avoid or reduce unnecessary car-based mobility	Strategy to increase the vehicle utilisation of transport modes	Strategy to shift the use of individual motorised transport	Strategy to improve the spatial distribution of traffic volume	Strategy to improve the temporal distribution of traffic volume	Strategy to improve the transport supply capacity	Strategy to reduce traffic accidents and their impacts	Strategy to improve integration between traffic-related activities	Strategy to reduce the disturbances of traffic flow
PT	Public Transport Measures										
1	Public Transport Network Improvement	T-O	◑	◑	●	●	◑	◑	○	◑	○
2	Public Transport Scheduling Improvement	T-O	◑	●	●	●	●	◑	○	●	○
3	Public Transport Accessibility Improvement	T-O/INFR	◑	◑	●	●	○	●	○	◑	○
4	Public Transport Capacity Improvement	T-O/INFR	◑	●	◑	◑	○	●	○	◑	○
5	Special Disaster Transport Services	T-O/ADMN	◑	○	◑	○	○	●	○	○	○
6	Public Transport Right-of-Way Prioritisation	T-O	◑	◑	◑	○	○	◑	●	○	◑
7	Public Transport Information Services	INFO	◑	◑	●	○	◑	◑	◑	●	◑
8	Public Transport Management Centre	T-O/INFO	◑	◑	●	◑	◑	◑	◑	●	◑
NMT	Non-Motorised Transport Measures										
1	Establishment of Pedestrian routes & Facilities	T-O/ADMN	◑	○	●	○	○	◑	◑	○	○
2	Establishment of Bicycle routes & Facilities	T-O/ADMN	◑	○	●	○	○	◑	◑	○	○
IMT	Individual Motorised Vehicle Measures										
1	Carpooling & other Ride Sharing Programs	ADMN	○	●	○	○	○	●	○	●	○
2	Car Rental Services	ADMN	○	●	○	○	○	●	○	●	○
3	Automobile Roadway Repair Service	ADMN	○	○	○	○	○	◑	●	○	○
4	Special Traffic Rules Enforcement	ADMN	●	○	○	◑	◑	○	●	●	●
MIM	Multimodal and Intermodal Transport Measures										
1	Economic or Preferential Incentives	T-O/ECO	●	●	●	●	●	●	○	○	○
2	Trip reduction & Land-use Modification Ordinances	ADMN	●	●	●	●	●	◑	○	◑	○
3	Road Network Control	T-O	○	○	●	●	●	●	●	○	●
4	Road Section Control	T-O	○	○	○	●	○	●	●	○	●
5	Improvement of Signalised Traffic Control	T-O	●	○	○	●	◑	●	●	○	●
6	Improvement of Non-signalised Traffic Control	T-O	●	○	○	●	◑	●	●	○	●
7	Improvement of Inter-modal and Parking Facilities	T-O/ADMN	○	●	●	◑	○	●	◑	●	○
8	Traffic & Disaster Information Service	T-O/INFO	●	●	◑	●	●	●	◑	●	●
9	Disaster Traffic Management Centre	T-O/INFO	◑	◑	◑	◑	◑	◑	◑	●	●
10	Work- Zone Coordination & Management Centre	T-O/INFO	○	◑	◑	◑	◑	◑	◑	●	●
FR	Freight Transport Measures										
1	City Logistics System	T-O/ADMN	○	●	○	○	○	●	◑	●	◑
2	Household Goods Delivery Transport System	T-O/ADMN	●	●	○	○	○	◑	◑	●	◑
3	Freight Traffic Operations Control	T-O/ADMN	○	○	○	◑	●	◑	●	○	◑

Note:

Directly applicable measures ●

Indirectly applicable measures ◑

Less applicable measures ○

Table 10-1: Example of possible application of TM measures in Delhi

35. Establishment of City Logistics System is proposed firstly for the use of small vehicles in the urban areas and secondly to ensure the optimal utilisation of freight capacities by reducing empty haulage of freight transport. This proposal necessitates the establishment of integrated freight complexes at the border locations of Delhi (along 5 National Highways) for the purposes of bulk-breaking for further distribution.
36. The establishment of Household Goods Delivery System by Food Supplies Department of Delhi is proposed in conjunction with Ration Shops in disaster-affected areas and a provision of distribution of food supplies and other goods through home delivery is proposed.
37. Freight Traffic Operations Control is proposed in order to avoid the freight traffic based on time and size of vehicles at five National Highways in Delhi (NH1, NH2, NH8, NH10, and NH24).

- **Traffic Incident Management**

38. The establishment of service points for the operation of Automobile Roadway Repair Service are proposed on National Highways in Delhi and other roads within urban areas.
39. The road accident and incident helpline system should be established under the road safety board. There is a need to evolve dedicated Road Accident Helpline System by integrating the existing fleet of CATS/PCR to provide back-up support to the system.

- **Work Zone Management**

40. The development of work-zones and Work-Zone Management System is proposed in the disaster-affected or prone areas. The long-term and short-term work zones should use management principles to reduce the duration of activities, modify the start and end time of activities; and use of synergies by sharing infrastructure and manpower. The work zones should also develop bicycle and walking plans within and outside the work-zones.

10.3 Summary

In this Chapter, the proposals are provided and categorised into 12 traffic management modules for the case study city, New Delhi. The proposals given for the traffic management modules provide a useful framework for TM strategies application in disasters. Considering the proposals for the case study city New Delhi, the possible measures were studied in context to disaster situations and are explained in Annexure J. Table 10-1 provides the applicable TM measures that form a part of different applicable TM strategies in cases of disasters in Delhi. In addition, applications of the selected nine TM strategies for the case study city- New Delhi are also explained in Annexure J.

11 Summary of Observations

This Chapter firstly provides the summary of various observations of this study. Secondly, it also highlights difficulties and limitations encountered during the process of conducting this study. Finally, it provides the scope of further research.

11.1 Main observations

Several research questions were answered in this dissertation. The research questions also provided orientation to the dissertation. The following sections provide the answers of research questions and brief conclusions of various chapters of this study.

Chapter 1 provided the motivations for conducting this dissertation, which are: (i) **inadequate recognition of the role of the transport system by disaster management**, (ii) **unprecedented traffic and transport problems in cases of disaster**, (iii) **High potential for the application of traffic management**, and (iv) **traffic management shortcomings**.

Chapter 2 answered the first research question "**What is state-of-the-art in disaster management?**" by providing an overview of disasters and disaster management processes. The occurrence of disaster is considered as culmination of a hazard in vulnerable conditions. While the natural hazards cannot be controlled, vulnerability to these hazards on the people and property can be substantially reduced. Vulnerable conditions can be described by the physical, social and demographic state, economic and environmental conditions. The selection criteria of disasters were: **geographical scale**, **warning time**, **deaths/injuries**, **generation of traffic demand** and **poor state of transport supply**. Transport situation in disasters, also described by resultant transport supply and total traffic demand, is critical in cases of Tornado/Hurricane, Earthquake, Tsunami, Flooding, etc. The analyses of disasters based on reported disasters in Year 2002, 2003 and 2004 concluded that:

- **Floods, Windstorms and Earthquakes are most frequent disasters**.
- **Earthquakes, Extreme weather conditions and Floods are disasters that account for most deaths**.
- **Floods, Drought and Windstorms affect the most people worldwide**.
- **Windstorms, Floods and Earthquakes affect the most countries economically**.

Disaster management is not a separate sector or discipline but an approach of solving disaster-related problems which impacts many sectors e.g. agricultural, industrial, environmental, social, etc. Thus, disaster management is the responsibility of all sectors, all organisations and agencies that may be potentially affected, involved or required in cases of disasters. **"Disaster management means a continuous and integrated multi-sectoral, multi-disciplinary process of planning and implementation of measures aimed at prevention & mitigation, preparedness, response and recovery of disasters"**. Many disaster-prone countries have defined the roles and responsibilities of involved organisations in their disaster management plans. **FEMA** and **DDMA** have defined 14 disaster management functions (also called disaster or emergency support functions) of various sectors. These disaster management functions can be activated as on need of disaster management.

The objectives of disaster management are:

- **to avoid or reduce the impacts of disasters,**
- **to assure prompt assistance to the victims**, and
- **to achieve rapid and effective recovery**.

Various objectives are considered and fulfilled in four broad phases of disaster management. Disaster management is a cyclic process and first phase of DM is focused on **prevention or mitigation** of disaster. This phase focuses on reducing the impacts of disaster on the community by preventing the occurrence of disaster completely else mitigating the impacts of disasters on the community to minimum. The second phase of DM focuses on **preparedness** of sectors and organisations in anticipation of disasters. The third phase focuses on the prompt **response** to disasters by various identified disaster management functions. The final phase of DM focuses on rapid and effective **recovery** from disasters. Recent disaster management plans adopt a contemporary approach in which activities related to prevention, mitigation, preparedness, etc. are implemented simultaneously.

The study on disaster management processes, acts, plans, and organisational-framework of India and Germany indicated comprehensiveness but did not adequately address the involvement of traffic management.

Chapter 3 answered the research question, "**What is state-of-the-art in traffic management?**" Traffic management has been applied in many countries under many different names such as **urban traffic management**, **transportation system management**, **verkehrs-system management**, **travel demand management**, **congestion management**, etc. Recently more comprehensive approach of traffic management is practised in many countries which address both the influence areas namely transport supply and traffic demand. According to Boltze, "**traffic management is aimed at influencing the traffic and transport through a bundle of measures to bring the traffic demand and transport supply in an optimised balance"**.

Traffic management has many strategic and operative objectives. The operative objectives of traffic management can be summarised in three basic impacts which are:

- **to avoid traffic**,
- **to shift traffic**, and
- **to control traffic**.

Eleven strategic objectives of TM were defined in this study which were also used to formulate the basis of the TM strategies,

- **to reduce the total traffic demand,**
- **to improve the vehicle utilisation,**
- **to improve the mode selection for certain trips,**
- **to improve the destination selection for certain trips,**
- **to improve the route selection for certain trips,**
- **to improve the time selection for certain trips,**
- **to improve the transport capacity,**

- **to reduce the frequency and fatality of accidents,**
- **to improve the traffic flow condition in case of long-duration activities,** and
- **to improve the traffic flow conditions in case of short-duration activities**.

Various traffic management modules were used, which are; traffic influencing processes or mechanisms available in the existing environment for the implementation of TM measures. The TM measure is defined as: **desired realisation of an action that creates traffic and transport influences towards the desired improvement of a desired transport situation**. TM Strategy consists of several TM modules and measures.

Traffic management measures were classified upon five transport modes categories which are: **Public transport**, **Non-motorised transport**, **Individual motorised transport**, **Multi-modal and inter-modal transport**, and **Freight transport**. In the past, traffic management was limited to traffic control and regulation of road traffic. Recently traffic management concepts are available which use a wide range of measures such as **administrative and organisational**, **economic**, **technical or operational**, and **informational measures**.

The time scale of traffic management can be **short-term**, **medium-term** and **long-term**. Similarly traffic management could be applied to create influences on traffic through static and dynamic traffic management. **Static traffic management does not adapt to the existing traffic conditions but aim to create traffic influences generally**. **Dynamic traffic management adapts to the current traffic conditions and modifies the current traffic condition**.

Several mechanisms of traffic and transport influences were studied. Some of them are:

- Avoiding traffic by **linking trips**, **substituting trips** and **modifying trips**.
- Shifting traffic to **alternate times**, **modes** and **destinations**.
- Controlling traffic by controlling the **transport network**, **transport modes** and **transport users**.

The prevalence of traffic management modules in the local area-of-application is required for the implementation of TM measures. **A traffic management module is an established traffic influencing process or a mechanism for the implementation of measures**. Twelve traffic management modules were studied comprehensively in context to requirements of TM measures.

The prerequisites of traffic management measures were studied, which are:

- **Social and organisational pre-requisites** are necessary to initiate institutional participation and public acceptance in anticipation of TM measures.
- **Technological pre-requisites** are necessary to meet the equipments and technology required for the TM measure implementation.
- **Economic pre-requisites** are necessary for the TM measures involving procurement of transport infrastructure and subsidies requirements of some cost-intensive measures.
- **Legal pre-requisites** are necessary for the TM measures involving strict enforcement of traffic rules and regulations. They also provide the basis of TM measures implementation.

Similar to disaster management, traffic management is also not a separate sector but an approach to harness the skills and resources across various stakeholders. The stakeholders are grouped as: **(i) Land authorities** (Federal, State, Regional, District and Councils), **(ii) Public transport operators** (Federal and State operated railways, public transport operators, air transport operators

and sea transport operators), **(iii) Service provider** (commercial provider, Radio, traffic operators, mobility centres, etc.), **(iv) Manufacturer/industry** (product and applications manufacturer, automobile industry, etc.), **(v) Transport User groups** (IMT user, PT user and service transport and commercial transport user) and, **(vi) Concerned groups** (residents). The other stakeholders include the transport planners and traffic engineers who provide consultation to the TM authorities.

The study on current literature on traffic management revealed that main goals of traffic management are related to **ensuring accessibility and mobility, safety and security of transport, economy of transport, and environment of transport**. However, literature also revealed that there are persistent differences among formulated goals and objectives. The differences were also found while estimating the impacts of TM measures from the perspective of different transport stakeholders. There are also counter-effective secondary impacts on the urban transport system due to implementation of some TM measures. Compatibility of TM measures and application problems in the real practice are some issues and problems of traffic management.

Literature revealed that in Germany the traffic management including transport infrastructure is highly standardised and developed. The German Planning Process provided effective framework of inclusion of traffic management (TM) into disaster management (DM). Traffic control and enforcement of traffic regulations influencing the transport supply are well implemented in Germany, although some difficulties of public acceptance could lead to limitations of demand-reduction measures. Traffic management and transport infrastructure in India is very poor. Recently efforts are made to manage huge traffic demand through transport infrastructure development. The rate of infrastructure development is slow and additional measures are required to promote traffic demand reduction, e.g. effective land use planning, pubic transport development, alternate working methods, etc. The lessons learned from the investigation of German traffic management for the application in India are:

- **Road classification** for effective maintenance and standardised implementation of traffic management,
- **Vehicle classification** to allow standardisation of vehicle equipments and technologies,
- **Effective enforcement of laws and regulations** to improve safety of traffic,
- **Traffic education and training** to improve driver behaviour,
- **Use of standardised equipments and technologies** for better integration and uniformity of use of traffic management,
- **Improvement in organisational structure** of traffic management, and
- **Development and patronisation of public and non-motorised transport**.

Chapter 4 answered the research question **"What is the integration-framework for traffic management integration into disaster management?"** by developing a new concept of integrating traffic management into disaster management. The study reflected that disaster management lacks the inclusion of traffic management as a tool and therefore traffic management is untrained, ineffective and unprepared in cases of disasters.

Similar to disaster management, traffic management in cases of disasters is oriented towards avoidance of disasters, preparedness for disasters and respond in disasters. Integration of TM into disaster mitigation phase revealed the following objectives:

- **Promotion of disaster management in formulation of transport plans**.

- **Promotion of disaster-ready design of transport system**.
- **Promotion of disaster-ready construction of transport infrastructure**.

Integration of traffic management into disaster preparedness phase revealed the following objectives:

- **Preparedness of transport infrastructure**.
- **Preparedness of traffic management systems**.
- **Preparedness of transport users and operators**.

The study revealed the necessity of adoption of above given objectives in disaster mitigation and preparedness in order to integrate traffic management into the transport developmental planning.

Integration of traffic management into disaster response and recovery phase revealed the following objectives:

- **Provision of transport accessibility and mobility in disasters**.
- **Provision of transport safety and security in disasters**.
- **Provision of economic transport system in disasters**.
- **Provision of environment-friendly transport system in disasters**.

The study investigated the similar orientation of TM objectives in disaster recovery, in which more emphasis is required to ensure the fulfilment of economy and environmental objectives.

The study also provided the sequence disaster management functions which revealed that disaster control (fire fighting, flood control, evacuation, etc.) and medical care are first activated disaster management functions. The next important DMF is the establishment of housing and shelters. After their establishment, other DMF provide response and recovery at the established housing and shelters.

In general, the developed framework provided the steps, phases and processes involved in the integration of TM into DM. For specific cases of disaster-affected or prone areas of India, transport sector must involve mitigation and preparedness measures to integrate transport planning, design and development of transport facilities for disaster mitigation and preparedness.

Chapter 5 answered the research question, **"What are traffic and transport problems and issues in disaster-affected or disaster-prone regions?"** Literature review and case studies were conducted to reveal the traffic and transport issues and problems in disasters which can be broadly classified into three types which are:

- **Disaster impacts on transport infrastructure**.
- **Disaster impacts on transport modes**.
- **Disaster impacts on transport users and operators**.

Disaster impacts the transport infrastructure i.e. roads, terminals and traffic control devices. Disaster also impacts the vehicles (transport modes) by impacting the vehicle condition and vehicle operation. The decision-making of transport users and transport operators is severely affected in disasters. Furthermore, the changes in the activity patterns of the affected people during disasters results in high traffic demand.

The prevailing boundary conditions of the disaster-affected or prone areas were studied to describe the transport development state. Four main issues derived from the transport development state are:

- **Legal and administrative issues**
- **Technical and operational issues**
- **Economic issues**
- **Organisational issues**

Legal and administrative issues of disaster-affected or disaster-prone areas are **lack of laws, regulations and ordinances for transport planning, design and construction**.

Technical and operational issues of disaster-affected or disaster-prone areas are **lack of TM tools, procedures and mechanisms**. They also include **lack of traffic education and training**.

Economic issues of disaster-affected or disaster-prone areas are **lack of funds for disaster-proof transport infrastructure and for alternate-equipments, technologies and subsidies**.

Organisational issues of disaster-affected or disaster-prone areas are **lack of organisational framework and lack of integration between traffic and disaster management stakeholders**.

The combination of problems related to disaster impacts on transport supply and demand, and the traffic and transport issues of disaster-affected or disaster prone areas resulted in the following manifested problems:

- **reduced primary and ancillary transport infrastructure capacity**,
- **loss of power and communications**,
- **inadequate transport modes**,
- **reduced vehicle performance,**
- **poor travel decisions and traffic violations**,
- **poor transport operations and management**, and
- **high traffic demand**.

The analysis of disaster transport problems and issues guided the formulation of goals and objectives of traffic management in disasters. These problems were briefly categorised into four TM problems categories viz. **Mobility and Accessibility problems**, **Safety and Security problems**, **Economy problems** and **Environmental problems**.

Transport Mobility and Accessibility problems

- **decrease in available transport modes,**
- **decrease in number of transport routes,**
- **decrease in transport capacity,** and
- **inequitable transport service**.

Transport Safety and Security problems

- **increase accident rate and fatality rate in inter-urban and urban network,** and
- **increase in response time to accident locations**.

Transport Economy problems

- **very high transport operating costs (fixed and variable costs),**
- **very high road maintenance costs,** and
- **very high subsidies**.

Transport Environment problems

- **very high gas emissions due to transport activities during disaster response and recovery phases,**
- **very high noise levels due to transport activities during disaster response and recovery phases,** and
- **very high consumption of energy resources for transport purposes during disaster response and recovery phases**.

Chapter 6 answered the research question **"What is the operational-framework of traffic management in cases of disasters?"** Considering the fact that transport policy makers and traffic managers operate the traffic and transport system under the set goals and objectives of daily traffic management, traffic management operational-framework was developed to provide the concept of operations in the disasters. The availability of operational-framework clearly provided the **vision statement**, **mission statements**, **goals**, **objectives**, **criteria** and **indicators** (in later chapters) of traffic management in disasters. This framework serves as a guide to traffic managers in the development and application of TM measures.

Vision statement

The vision of traffic management as an aspect of disaster management was formulated as: **"to ensure the safe, quick and efficient movement of people and goods on the transport system, irrespective of any disaster"**.

Mission statements

Sustainability issues were addressed in the mission statements which are:

- **to preserve the societal values,**
- **to preserve the natural and built-up environment,** and .
- **to preserve the economics of the region**.

Goals of Disaster Traffic Management

The goals of disaster traffic management were developed to address the key problems and issues in disaster-affected or disaster-prone areas which are:

- **to ensure the quick accessibility and adequate mobility of transport in disasters**.
- **to ensure the safety and security of transport in disasters**.
- **to ensure the economy of the transport system in disasters**.
- **to reduce the environmental impacts of transport in disasters**.

Based on the above stated goals, more specific and measureable objectives of disaster traffic management were developed. The criteria to measure the objectives were also defined and the respective indicators were given for e.g. the equitable transport objective is measurable by criteria of fare structure, tax burdens due to subsidy, transport service quality, travel opportunities, etc. and

are expressed in per capita, per kilometre, per person-kilometre, per trip, per peak period or per tax subsidy.

The economy and environment goals and objectives are important to ensure the sustainability of disaster management including traffic management.

Chapter 7 answered the research question **"Which traffic management measures are effective and applicable in cases of disasters?"** The identification of 27 TM measures for traffic and transport problems and issues in disasters was based on disaster case studies (especially in India) and other technical as well as academic publications. The measures were based on their recorded effectiveness in many disasters-affected and disaster-prone countries. This chapter proposed a multi-criteria assessment model to validate the effectiveness and the applicability of 27 pre-selected measures.

The qualitative assessment of TM measures conducted two main qualitative assessments: (i) effectiveness assessment of TM measures and (ii) difficulties assessment of implementation of TM measures. The first assessment involved the estimation of relative weights of importance of TM goals and difficulty factors (factors of assessment). Estimation of subsequent TM objectives and difficulty criteria was also conducted. The assessment involved a group of chosen traffic experts for providing their opinions on the importance of TM goals, difficulty factors, TM objectives and difficulty criteria. This assessment involved a comprehensive questionnaire for obtaining opinions and these opinions were calculated as relative weights of importance using **Analytic Hierarchy Process (AHP)**. These relative weights were then fixed for the further assessments.

The result of the assessment of relative weights of importance indicated the following: (i) **the transport accessibility and mobility factor was rated as the most important factor which had a relative weight of 38%**, (ii) **the transport safety and security factor was rated as the second important factor which had a relative weight of 30%**, (iii) **the transport economy factor was rated as the third important factor which had a relative weight of 19%**, and (iv) **the transport environment factors was rated as the fourth important factor which had a relative weight of 13%** respectively. Similarly in terms of difficulty, **the factor of transport cost was rated as most difficult factor (31%)** followed by **technical systems (27%)**, **institutional participation (24%)**, and **public acceptance (18%)**.

The second assessment involved **a self-conducted assessment** of all 27 measures for effectiveness and difficulties of implementation in typical disaster-prone areas. The scales were set from 0 to 3 in increasing order of effectiveness and difficulty to validate a measure.

A **qualitative assessment model** was developed to provide the **effectiveness scores** and **difficulty scores** of all 27 measures. These effectiveness and difficulty scores provided a basis of formation of priority classes of 27 measures. The results indicated high effectiveness of all 27 pre-selected TM measures, although medium to high difficulties of implementation were observed. Six priority classes were formed which provided first and second recommended measures. The first recommended measures included 13 measures. Of which most recommended public transport measures are: (i) **Public Transport Network Improvement**, (ii) **Public Transport Capacity Improvement** and (iii) **Public Transport Information Services**. Both NMT measures qualified for first recommended measures, namely (i) **Establishment of Pedestrian routes & Facilities** and (ii) **Establishment of Bicycle routes & Facilities**. Three measures qualified as first recommended measures under IMT, namely (i) **Carpooling & other Ride Sharing Programs**, (ii)

Car Rental Services, and (iii) **Automobile Roadway Repair Service**. Three measures qualified as first recommended measure under MIM, namely (i) **Improvement of Signalised Traffic Control**, (ii) **Improvement of Non-signalised Traffic Control**, and (iii) **Improvement of Inter-modal and Parking Facilities**. Last but not least, two FT measures were qualified for first recommended measures, namely (i) **Household Goods Delivery Transport System** and (ii) **Freight Traffic Operations Control**.

The measures that did not qualify either for the first or the second recommended measures (7 in number) due to their high difficulty scores were selected for applicability improvement through methods (i) **to reduce costs of implementation**, (ii) **to reduce the use of advanced technical systems**, (iii) **to improve the stakeholder's participation**, and (iv) **to increase the public acceptance** to disqualified measures.

The assessment of the effectiveness and applicability of measures are effective tools of decision-making by policy planners including traffic managers. The inferences of the assessment should be utilised to decrease the difficulties of measures by proposing applicability improvement methods.

Chapter 8 answered the research question **"Which traffic management strategies are applicable in cases of disasters?"** The measures recommended for application were based on effectiveness and difficulty assessments and were checked for the compatibility with other measures. This is due to incompatibility issues within TM measures and the requirements of other complimentary measures for conflict-solving. The measures are applied in conjunction for their synergy effects and conflict-solving effects, together with a pre-defined action plan. Such groups of measures are referred in this study as traffic management strategies. A disaster traffic management strategy was defined as **a pre-defined action plan for the implementation of a set of traffic management measures to improve a specific disaster transport situation**.

Nine TM strategies were formulated to address the traffic management vision, mission, goals and objectives, of which **five traffic demand reduction strategies** and **four transport supply augmentation strategies** were formulated. The formulation of strategies included all pre-selected **basic measures** irrespective of their effectiveness and difficulties of implementation. **Complimentary measures** were accordingly proposed to improve the applicability of medium to highly difficult measures.

Strategy to avoid or reduce unnecessary car-based mobility

This strategy aimed at **reducing the unnecessary need to travel by automobile mainly cars**. This strategy focuses on evolving new mechanisms for reducing trips by more favourable land use and by influencing the traffic demand to be more effectively fulfilled by **linking trips** (e.g. trip chaining) , **substituting car-trips by technology** (e.g. trip reduction and land use modification ordinances) and by **modifying trips** (e.g. household goods delivery system).

Strategy to increase the vehicle utilisation of transport modes

This strategy is aimed at **using the full capacity of existing transport modes** and hence reduces the total number of passenger and freight trips. This strategy increases the vehicle utilisation without increasing the traffic volume on roads. The important measures are: **carpooling and other ride-sharing programs** and **city logistics system** (freight coordination programs) for the success of this strategy.

Strategy to shift the use of individual motorised transport

This strategy is aimed at shifting the use of IMT modes by **promoting the use of PT, NMT and MIM modes**. This strategy will reduce the negative impacts of using IMT modes such as congestion, accidents, high costs and high pollution. The important measures are: **establishment of pedestrian (and cycling) routes and facilities** and **economic or preferential incentives of using public transport (alternate modes)**.

Strategy to improve the spatial distribution of traffic volume

This strategy is aimed at **increasing the transport capacity** (roads and other infrastructure) by shifting traffic spatially to different routes and destinations. This strategy will increase the required capacity by using existing transport capacities more effectively. This strategy could be applied dynamically based on dynamic transport situations. The important measures are: **land-use modification ordinances**, **Road network control** (automobile- restricted zones, access restrictions and modes segregation) and **Improvement of signalised traffic control** (traffic signal control).

Strategy to improve the temporal distribution of traffic volume

This strategy is aimed at **decreasing the traffic volume in peak-demand hours**. This strategy will influence the traffic by modifying the start and end times of trips. The important measures are: **economic or preferential incentives and disincentives** (alternative work schedules/flexible work schedules/compulsory closing of public and private establishments), **freight traffic operations control**, establishment of **work- zone coordination and management centre** and the provision of **traffic and disaster information service**.

Strategy to improve the transport supply capacity

This strategy is aimed at **augmenting the transport supply capacities** i.e. transport infrastructure and operation capacities. The infrastructure capacities are improved by adding fleet for public as well as freight transport. The operation capacities are improved by infrastructure sharing and special transport service agreements. The important measures are: **special disaster transport services** (agreements on transport service operations), **public transport accessibility improvement**, **public transport scheduling improvement** (vehicle rotation plans) and **public transport capacity improvement**.

Strategy to reduce traffic accidents and their impacts

This strategy is aimed at **reducing both the accident and fatality rate of traffic accidents**. This includes the reduction of negative impacts of traffic accidents such as congestion and probability of secondary disasters. The important measures are: **special traffic rules enforcement** (vehicle improvement), **improvement of non-signalised traffic control** (speed control, visibility enhancement) and establishment of **work-zone coordination and management centre**.

Strategy to improve integration between traffic-related activities

Three main influences of this strategy are:

- **integration of multiple transport modes**,
- **modification of the use of transport modes**, and

- **integration of multiple activities that generate traffic**.

The important measures are: **public transport scheduling improvement** (synchronisation of travel time tables), **trip reduction ordinances** (inter-operable transport and trip chaining), coordination between **work- zone coordination and management centre** (manual traffic control) and **disaster traffic management centre**.

Strategy to reduce the disturbances of traffic flow

This strategy addressed **traffic and transport problems due the inclement weather conditions during disasters**. This strategy will reduce the impacts of disturbances in traffic flow due to inclement weather, poor driving behaviour and non-incident related vehicle breakdowns. The important measures are: **special traffic rules enforcement** (vehicle improvement, speed limits, etc.), **road section control** (lane management, speed zoning), **improvement of signalised traffic control** (traffic signal control), **improvement of non-signalised traffic control** (visibility enhancement) and operation of **traffic and disaster information service**.

Chapter 9 provided an application of scenario development techniques to develop traffic management scenarios. **Traffic management scenario is defined by a combination of transport situation and traffic management strategies**. The study categorised the transport situation factors into: (i) **disaster impacts on transport supply and demand**, (ii) **transport development state of the disaster area**, and (iii) **transport operations performance of transport system during disasters**. The criteria, quantitative and qualitative indicators to define the transport situation based on transport situation factors were also established.

The study of relationships between the transport development state and disaster impacts on traffic demand revealed that **traffic demand condition is dependent on the social, environmental, and political development state**. Similarly, **transport supply condition is dependent on technological and environment development state**.

The study of relationships between the transport development state and transport operation performance revealed **impact of social development state on skills utilisation level, transport information level of transport users, non-users and operators**. **Technological development state impact all criteria of transport operation performance namely fleet, capacity and skills utilisation level, information level of all groups of users and operators, and transport service regularity, punctuality, and sequence**. Similar interrelationships were established for other transport situation factors.

Disaster transport situation model was based on cumulative weighted scores obtained from the summation of multiplication results of situation rating and their corresponding relative weights of importance. The transport situation of Nagapattinam tsunami disaster area was estimated based on the chosen transport situation factors. The results showed the worst situation level (SL A) with higher cumulative score.

Traffic management scenario assessment matrix revealed the development of four TM scenarios based on five situation levels (SL A to E) and three levels TM Strategies.

Four main decisions were derived from the assessment of transport situations:

(i) Common traffic management strategies required for all disasters are related to the **increase of vehicle utilisation**, **improvement of spatial distribution of traffic volume**, **improvement of transport supply capacity** and **reduction of disturbances of traffic flow**, (ii) The TM measures required for the formulation of TM strategies were studied and the most common measures

required for most disasters are related to improvement of **public transport network, scheduling, accessibility and capacity**. In IMT category, **operation of car sharing and car rental services** is commonly required. The measures such as **provision of economic and preferential incentives, implementation of trip reduction and land use modification ordinances, improvement of signalised and non-signalised traffic control, and improvement of inter-modal facilities** are commonly required MIM category measures. The **operation of City Logistics System and freight traffic operation control** is common in FT category measures, (iii) Although TM measures namely **Road Network and Section Control**, and **Traffic and Disaster Information Service** are commonly required measures yet these measures were inapplicable due to high level of difficulties, (iv) The applicability improvement of such measures were provided in four areas of transport sectors namely **transport economics**, **traffic technology**, **transport politics**, and **traffic education**.

Chapter 10 provided the proposals for the improvement of available TM modules for a case study city of New Delhi. Furthermore, the proposals of application of TM strategies as well as TM measures were also made.

11.2 Contributions, Limitations, and Scope of further research

Contributions of the study

- The study contributed to the development of understanding on disasters characteristics and disaster management process.
- The definitions of Traffic Management, TM module, TM measure and TM Strategy were defined in relation to disasters. This study provided various traffic management modules for the application of TM measures.
- The development of integration-framework provided the participation of transport stakeholders, and the level of application of traffic management including other sectors of transport in disaster management planning and developmental process.
- The development of operational framework of traffic management into disaster management contributed to the formulation of vision statement, mission statements, goals, objectives, criteria and indicators of traffic management in cases of disasters.
- The study identified the TM problems and issues in cases of disasters. The study provided the disaster impacts on the components of transport system and presented the traffic and transport issues due to prevailing boundary conditions of disaster-affected or prone areas.
- This study provided a list of basic and complimentary TM measures for application in disasters. The qualitative assessment method for assessing TM measures is developed as a useful tool for decision-making. The results of assessment provided the priority of measures in terms of their effectiveness and difficulties of implementation of measures.
- The TM strategies were formulated based on assessed TM measures, 5 TM strategies were formulated for traffic demand reduction and 4 TM strategies were presented for transport supply augmentation. These TM strategies were recommended as means to fulfil TM vision, missions, goals and objectives especially in cases of disasters.

- The scenario planning techniques were used to qualitatively develop the transport situations and subsequently disaster transport situation assessment model was developed to define various levels of situations (transport situations) in disasters.
- The proposals of application of developed strategies for the case study city New Delhi were presented.

Difficulties in the study

- Large variations of traffic and transport problems due to varied impacts of disasters on transport system.
- Large variations of the application of TM measures also resulted in assessment problems by several traffic experts.
- Limited availability and dissemination of qualified data due to confidentiality of disaster related data.
- Lack of quantitative data resulted in rejection of quantitative models. Therefore, the assessment results could not be verified through quantitative evidence.
- Lack of quantitative assessment models and computerised assessment tools limited the scope of application of the developed qualitative assessment model e.g. sensitivity analysis.

Limitations of the study

- Due to data gaps, comparative studies were limited on available criteria and indicators.
- Due to the unique situation of transport situations in disasters, basic assumptions were made which were difficult to validate without quantitative evidence.
- Due to lack of quantitative data, quantitative assessment of TM measures could not be performed.
- Due to unavailability of computerised tools of assessment, the inclusion of some factors of assessment and the scale of assessment was limited.
- Unavailable assessment tools limited the assessment to TM measures and TM strategy assessment could not be conducted.
- The limited secondary data (e.g. tsunami disaster) provided limited understanding of disaster and traffic characteristics.

Scope of further research

Further research is required to study the large scale research problems especially traffic and transport problems, TM Strategies, Disaster and traffic management processes, assessment models for TM scenarios including assessment models for TM strategies and transport situations.

- A comprehensive study on the practical applications of developed integration framework and operational framework in disaster-affected or disaster-prone region/s is recommended.
- Quantitative assessment is required for assessing the effectiveness and difficulties-of-implementation of measures in cases of disasters.

- Quantitative assessment is required for the traffic management strategies assessment.
- Quantitative assessment models are required for assessing the level of situation pertaining to specific transport situations in cases of disasters.
- Refinement of the developed assessment model is suggested by explicitly modelling possible scenarios.

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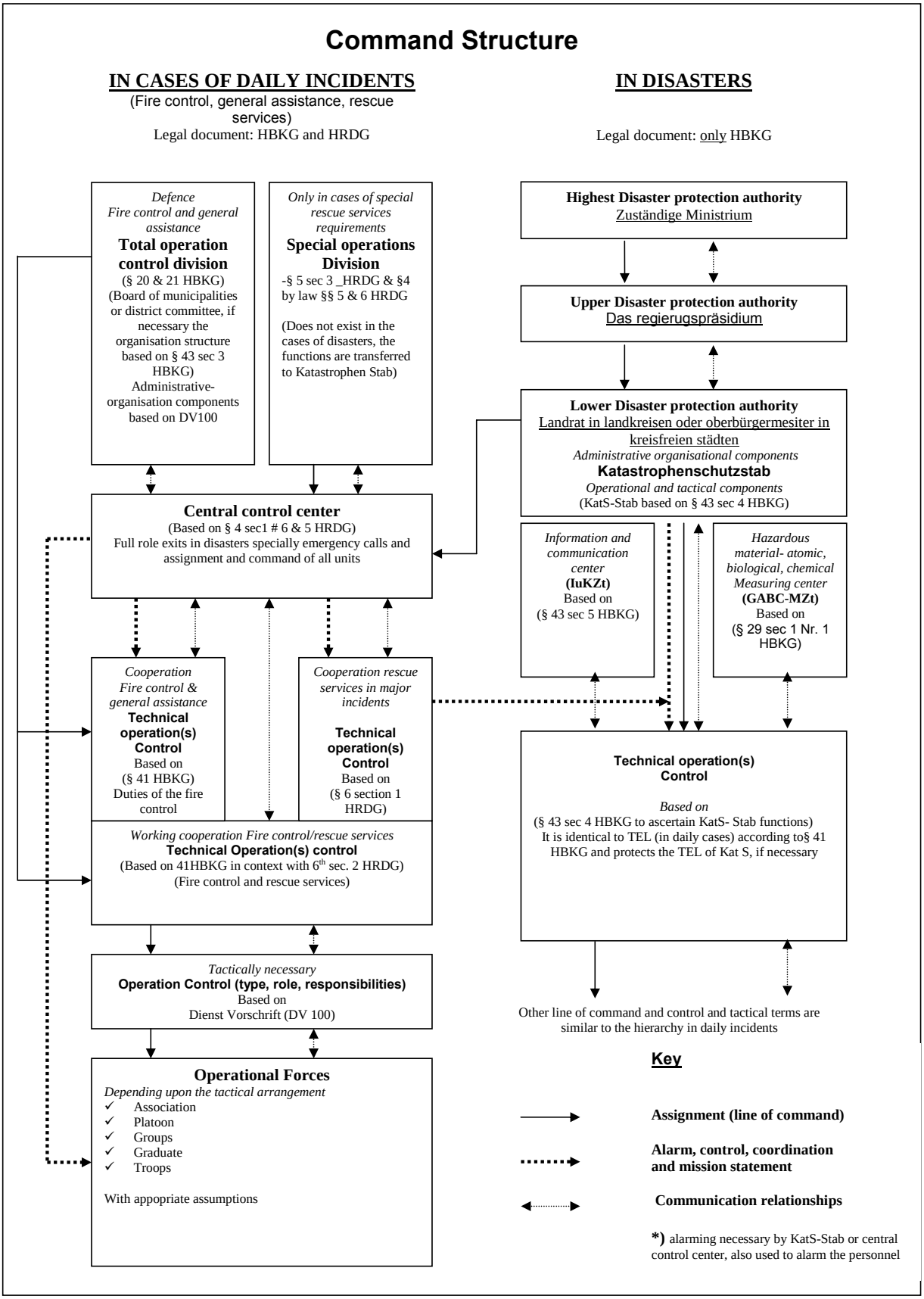
Annexures



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Annexure A: Command Structure of German Disaster Management

Annexure B: Description of Traffic Management Measures

Public Transport Measures

1. Public transport network improvement

This measure is aimed at extending, modifying or re-routing the public transport routes to improve the accessibility of people to the public transport in disasters. In cases where public transport is a predominant transport mode, it will be the operator's obligation to provide public transport services to cover the maximum service area with the least dead mileage in disasters. The reduction of travel time and vehicle operating costs are secondary benefits of public transport network improvements. This measure is applied to both fixed and flexible route transit. The application of this measure is only limited to the existing public transport supply (infrastructure, fleet and control equipments) including special disaster transport. This measure does not include investments on construction of any terminal, stops or interchanges, procurement of fleet or control equipment for purposes of route extension or re-routing.

Complimentary measures: Public transport scheduling improvement, Public transport accessibility improvement, Public transport capacity improvement, Special disaster transport services, Public transport right-of-way prioritisation, Public transport information services, Public transport management centre, etc.

2. Public transport scheduling improvement

This measure focuses on alteration of schedules (arrival and departure time at the stops/stations), service frequency (vehicles per hour), total service time, travel roster plans, vehicle rotation plans, stop frequency (stops per kilometre), etc. in order to maximise the utilisation of public transport service. In disasters requiring evacuations, this measure will modify the time schedules of public transport to meet the high traffic demand in disasters. This measure includes the reduction of some minor stops in order to provide express service and integration with the other modes through the multimodal integrated time scheduling concept. This concept refers to possible connections amongst different modes of public transport for the purposes of increasing the fleet utilisation, trip reduction and better connectivity. The German synchronised time table concept popularly known as 'Integraler Taktfahrplan' is implemented for connecting various public transport modes at multiple timed transfer junctions (ITF junctions). The concept of synchronising of time-tables requires a comprehensive fixed-interval, timed-transfer, multi-junction system for the systematic coordination of different transport modes. Multi-modal integrated time scheduling for network-wide public transit operations is not considered except on possible transport routes due to its inherent limitations.

In some cases, the scheduling improvement would demand more fleet, which could be fulfilled through the implementation of other complimentary measures (operation of special transport service). Otherwise, this measure will not include any investment on any new road construction or procurement of control equipments for purposes of modified scheduling.

Complimentary measures: Public transport network improvement, Public transport accessibility improvement, Public transport capacity improvement, Special disaster transport services, Public transport right of way prioritisation, Public transport information services, Public transport management centre, Economic or preferential incentives, Improvement of inter-modal and parking facilities, Traffic & disaster information service, etc.

3. Public transport accessibility improvement

This measure focuses on safe and convenient access to public transit stops and stations. This measure will include the provisions of the following:

- **to improve the public transport feeder routes**
- **to improve the feeder services to the public transit**
- **to improve the inter-modal and parking facilities**

This measure involves the estimation of total public transport demand followed by the determination of feeder routes. In cases where the feeder routes are unable to link to the public transit lines directly, this measure would propose their link and service to the nearest Para-transit service. This measure also supports the establishment of pedestrian and bicycle routes connecting to the nearest public transit as it will increase the public transport rider-ship. This measure includes minor modifications of connections between inter-city and city transport at public transit stations (inter-state and state bus terminals, local and regional train stations, etc.) to provide adequate accessibility. This measure also includes the improvement of connections to the public transit by improving the inter-modal and parking facilities.

Complimentary measures: Public transport network improvement, Public transport scheduling improvement, Special disaster transport services, Public transport right-of-way prioritisation, Public transport information services, Public transport management centre, Establishment of pedestrian/bicycles routes and facilities, Car rental services, Carpooling and other ride sharing programs, Personalised para-transit service, Land-use modification ordinances, Improvement of Inter-modal and parking facilities, etc.

4. Public transport passenger capacity improvement

This measure refers to the provision of increasing the passenger capacity of public transport modes such as buses, tram, trains, etc. through the use of high-capacity public transport vehicles such as double-floor buses, use of additional units in buses, use of extra coaches or wagons in trains, trams, light rail transit, etc. The implementation of this measure is intended to increase the passenger capacity and the rider-ship of public transport, thereby reducing the total number of vehicle trips during disasters. The availability of vehicle technology and adequate economic resources for procurement of additional wagons, trolley units, locomotives, etc. is necessary for the implementation of this measure.

Complimentary measures: Public transport accessibility improvement, Special disaster transport services, Public transport right-of-way prioritisation, Public transport information services, Public transport management centre, Economic or preferential incentives, Trip reduction & land-use modification ordinances, etc.

5. Special disaster transport services

This measure will increase the mobility and accessibility of people to public transport by providing the operation of two transport services, inter-state transport service and personalised para-transit service. The inter-state transport service will provide public transport operation on routes where high public transport demand exists, and less availability of transport fleet. This service, as in other public transport service during disasters, will either be subsidised by the governments or absolutely free. The unaffected neighbouring counties, states or even countries, and transport operators will participate in a joint agreement which will allow different operators to operate in the disaster affected region.

The personalised para-transit service is also aimed at providing the demand-responsive public transport service through the operation of low capacity vehicles such as minibuses, taxis, motorcycles, tri-cycles, etc. This measure proposes the additional operation of para-transit service focusing mostly on the needs of mobility-disabled people such as the old and the physically-challenged who are unable to access transport in disasters. This service will serve people with no proper access to public transport and these who are non-drivers due to poor car ownership. This service will be highly personalised suiting the needs of people in terms of flexibility of time, location, destination, route and a limited possibility to carry their necessary belongings.

Complimentary measures: Public transport accessibility improvement, Public transport right-of-way prioritisation, Public transport information services, Public transport management centre, Economic or preferential incentives, Trip reduction & land-use modification ordinances, etc.

6. Public transport right-of-way prioritisation

This measure is aimed at establishing a public transport priority by assigning right-of-way on corridors, intersections, entry points and exit points. This measure is an example of vehicle to vehicle segregation for enhancing the safety of other road users and of improving mobility in disasters. This measure supports the integrated time scheduling to provide better connectivity to other modes using the principles of fixed time transfer. This measure is implemented while not contradicting the usage of the triage system of operations followed during disaster. In this measure, the public transport routes and lanes will be established by the public transport operator in coordination with the state transport and traffic management authorities. This measure will require minor modifications of public transport network and signalised traffic control. This measure will provide sufficient road markings to segregate the public transport from other transport modes. It will not provide physical separation to the public transport except in special circumstances due to limitation of time. The right-of-way will be assigned for different time periods after due consideration of the characteristics of roads and intersections at various locations within and outside city limits.

Complimentary measures: Public transport network improvement, Public transport scheduling improvement, Public transport accessibility improvement, Special disaster transport services, Public transport information services, Public transport management centre, Establishment of pedestrian routes & facilities, Establishment of bicycle-routes & facilities, Special traffic rules enforcement, Economic or preferential incentives, Trip reduction & land-use modification ordinances, Improvement of signalised traffic control, Improvement of non-signalised traffic control, Improvement of inter-modal and parking facilities, etc.

7. Public transport information services

This measure is aimed at improving the information level of transport users, non-users and operators. This service patronises the use of public transport by providing adequate, precise and timely information to change the travel behaviour of the transport users and potential transport users. The coordination of information sharing amongst transport operators is a pre-requisite to integrate the public transport trips. This information service will aid various transport operators in multi-modal integrated time scheduling (see Integraler taktfahrplan) which will result in the reduction of the total number of trips.

The public transport information services will provide static and dynamic information to travellers. The static information service will provide planned information about transport mode, service area, network, stop location, time schedule, connection possibilities, costs, etc. This information can be provided through public transport information kiosks, maps, telephone inquiry services, internet

services, text messages on televisions, etc. The dynamic information services consist of providing real time information to the travellers. This service will provide the current status of public transport such as arrival and departure times, possible detours, new schedules and other public transport operation conditions. This information can be provided through real-time communication media, automatic vehicle location system, and dynamic voice or text messages on-board or at transit stops/stations, radio, or mobile phone. The dissemination off dynamic information is based extensively on the economic and technological development state of the disaster affected area. In cases, where such technology, costs or information does not exist, this measure will not be applied and emphasis will be made to use the conventional forms of communications for information collection and dissemination.

Complimentary measures: Public transport network improvement, Public transport scheduling improvement, Public transport accessibility improvement, Special disaster transport services, Public transport management centre, Traffic & disaster information service, Disaster traffic management centre, Work zone coordination & management centre, etc.

8. Public transport management centre

This measure is aimed at creating the public transport management centre to aid the public transport operations during disasters. This measure includes the formation of an organisation, provision of infrastructure and the rules of operations. This measure will propose the levels of coordination and organisation of public transport at political, regional and organisational level. The PTMC will play an important role in the collection and dissemination of public transport information. The other functions of public transport management include the following:

- **public transport network planning**
- **public transport operation planning**
- **public transport signal management**
- **public transport safety management**
- **city centre access management**

The PTMC will be essentially a public agency or a state-owned organisation, in which public transport will not be fully decentralised (e.g. Verkehrsverbund in Germany or PTMCs in Hanoi and Hochminh City of Vietnam).

Complimentary measures: Public transport network improvement, Public transport scheduling improvement, Public transport accessibility improvement, Public transport capacity improvement, Public transport information services, Traffic & disaster information service, Traffic incident and disaster management centre, Work zone coordination & management centre, etc.

Non-motorised transport measures

9. Establishment of pedestrian routes & facilities

This measure is aimed at ensuring adequate and safe pedestrian routes to the nearest public transit or an inter-modal facility such as bus and rail stops, bus and rail terminals, etc. It includes the provision for using all pedestrian facilities such as ramps, crosswalks, overpasses, underpasses, pedestrian stops, etc. In disasters where the adequate pedestrian facilities cannot be provided, it will provide the basic infrastructure and facilities for pedestrian mobility and safety. Whereas in cases where high potential of non-motorised transport and low impact of disaster on

pedestrian routes exists, this measure will promote a network of pedestrian routes for accessibility to important land uses within the affected disaster area. In order to achieve adequate pedestrianisation during disaster, adequate pedestrian safety-enhancing measures will be implemented in anticipation.

Complimentary measures: Public transport network improvement, Public transport accessibility improvement, Public transport right-of-way prioritisation, Establishment of bicycle-routes & facilities, Economic or preferential incentives, Traffic & disaster information service, Disaster traffic management centre, Work zone coordination & management centre, etc.

10. Establishment of bicycle routes & facilities

This measure is aimed at ensuring adequate and safe bicycle routes to the nearest public transit, inter-modal facility and other important places. This measure also focuses on the provision of bicycle parking facilities such as bike stations, racks, etc. In disasters, bicycle lanes are often ineffective due to violations of their use by other traffic movement and parking. This measure will propose exclusive right-of-way (separate routes) for bicycles to segregate bicycle- automobile traffic for better safety. This measure does not advocate the construction of hard-metalled road but proposes the planning and establishment of bicycle-friendly routes. It also includes facilities which prevent conflicts with other traffic at signalised and un-signalised intersections.

Complimentary measures: Public transport network improvement, Public transport accessibility improvement, Public transport right-of-way prioritisation, Establishment of bicycle-routes & facilities, Economic or preferential incentives, Trip reduction & land-use modification ordinances, Improvement of signalised traffic control, Improvement of non-signalised traffic control, Traffic & disaster information service, Disaster traffic management centre, Work zone coordination & management centre, etc.

Individual motorised transport measures

11. Carpooling and other ride sharing programs

This measure consists of carpooling schemes and ride sharing programs which discourage the use of single occupancy vehicles (SOV) during disasters. The measure is intended to reduce the number of vehicle trips which results in minimising traffic congestion, pollution, travel costs, etc. Carpooling is a shared use of a car for the purposes of travelling to a common destination or on a common route. This is often practiced by people who each have a car but travel together to save the fuel costs and in the interest of socio-environmental benefits. With the extensive outreach of internet and intelligent software programs, the carpooling or ride-sharing is an effective measure to reduce the use of single occupancy vehicle trips. Ride-sharing bears a high potential for transporting people to common destinations during the disaster for evacuation and re-entry of disaster traffic. Carpooling or ride-sharing can be implemented through online programs or self made programs. The carpooling programs also support the functions and operations of HOV lanes.

Complimentary measures: Public transport accessibility improvement, Car rental services, Automobile roadway repair service, Special traffic rules enforcement, Economic or preferential incentives, Trip reduction & land-use modification ordinances, Improvement of inter-modal and parking facilities, Traffic & disaster information service, Disaster traffic management centre, Work zone coordination & management centre, etc.

12. Car Rental Service

The car rental service is aimed at renting a car to the potential car-user on a need basis to enhance the mobility of people. The application of this measure will involve an agreement between

the state transport authorities and the car rental services for their obligation to offer such services during disasters. This measure will minimise the transport deficit during a disaster which has occurred due to vehicle damages. The operation of this service will be fully privatised although the control and monitoring of operations will be provided by the state transport authorities. The fares chargeable or the revision of fares by the car rental service provider will be calculated by state transport authorities after due consideration of socio-economic profile of the disaster affected or prone area. This service will greatly help the mobility-disabled groups especially those groups due to poor car ownership and those groups in low public transport accessibility areas. The car rental services will be nominally priced but in exceptional cases it could be subsidised. Although this service is meant for the groups mentioned above, this service may be used by other groups as well.

Complimentary measures: Public transport accessibility improvement, Carpooling & other ride sharing programs, Automobile roadway repair service, Special traffic rules enforcement, Economic or preferential incentives, Trip reduction & land-use modification ordinances, Improvement of inter-modal and parking facilities, Traffic & disaster information service, Disaster traffic management centre, Work zone coordination & management centre, etc.

13. Automobile Roadway Repair Service

This measure is aimed at providing the automobile repair service in cases of vehicle breakdowns on motorways. In countries where such services are still not prevalent, this measure will focus on setting the mobile repair operation services. This service will normally include repair, towing and recovery of primarily individual motorised transport modes but in exceptional cases it could be applied to other transport modes as well. This service will strategically locate various automobile roadway repair centres so that any location could be reached in minimum amount of time. It will also provide a toll-free-number facility that will assist the motorists with trouble related to vehicles. This service will run a sizeable fleet of mobile mechanics to assist drivers. The towed vehicle will be taken to the garages for the repair and recovery of the vehicle. The operation of this service will be fully privatised although the control and monitoring of operations will be provided by the state transport authorities. The cost of operation of service will be calculated by state transport authorities after due consideration of socio-economic profile of the disaster-affected or disaster-prone area.

Complimentary measures: Carpooling & other ride sharing programs, Automobile roadway repair service, Special traffic rules enforcement, Economic or preferential incentives, Trip reduction & land-use modification ordinances, Traffic & disaster information service, Disaster traffic management centre, Work-zone coordination & management centre, etc.

14. Special traffic rules enforcement

This measure consists of set of traffic rules to control and monitor the vehicles, drivers and road users. The set of rules in this measure are intended to enhance the safety of vehicles, drivers and road users. The success of this measure will depend on strict traffic law enforcement environment and public acceptance to the new rules and regulations. The following are some examples of special traffic rules that will be enforced during disasters:

- **Vehicle improvement**: This regulation controls and monitors the adaptability of vehicle in bad weather conditions during disasters. The intended impact of this measure is the vehicle improvement through the practises such as installation of winter tyres & tyre chains, regular

vehicle checkups, fog lights installation, vehicle illumination and other special vehicle equipments. The vehicle improvement practices can greatly increase the vehicle traction and manoeuvrability which pose a big threat during bad weather conditions prevailing in disasters. The enforcement of this rule will result in retention or seizure of vehicle in cases where the required vehicle improvements are not made. The provision of supportive infrastructure for vehicle improvement such as garages, automobile repair stations, automobile parts, etc. will be necessary for the success of this measure. The public awareness and acceptance to follow the new traffic rules and regulations are necessary for enforcement of this measure.

- **Speed limits**: This regulation controls the driver's behaviour by imposing safe speed limits for various classes of vehicles that ply the road during bad weather conditions in disasters.
- **Access restrictions**: This regulation controls the traffic by restricting the use of certain areas permanently for vehicles or different time periods.
- **Overtaking restrictions**: The regulation controls the driver by prohibiting the vehicle-overtaking on various road sections which pose a serious threat of accidents in bad weather road conditions.
- **Parking restrictions**: This regulation will control the road user by restricting the parking of vehicle at certain 'no parking areas'.
- **High occupancy vehicles priority system (HOV)**: This regulation will provide the priority of HOV over single occupancy vehicles (SOV) wherever possible.
- **Disaster traffic priority system**: This regulation provides priority of disaster vehicles over any other classes of vehicle during disaster at junctions, corridors, entry or exit points, etc. The priority system is intended to optimise the use of limited transport resources in cases of high traffic demand. This system is used to control traffic based on priorities fixed from tentative tasks that come first in order of implementation or occurrence. The priorities will change and adapt depending upon disaster-type and its impact on people. The priority rules will be set up for each disaster type or category for urgent traffic (medical care and disaster control) and non-urgent traffic (media, research, disaster tourism, etc.). The setting of priority would conform to concepts like the triage system used by medical care and disaster control personnel. In order to reveal traffic priority, differently coloured triage tags or coloured flagging will be used along with different lighting.

Complimentary measures: Carpooling & other ride sharing programs, Economic or preferential incentives, Trip reduction & land-use modification ordinances, Road network control, Road section control, Improvement of signalised traffic control, Improvement of non-signalised traffic control, Improvement of inter-modal and parking facilities, Traffic & disaster information service, Disaster traffic management centre, Work-zone coordination & management centre, etc.

Multi-modal and inter-modal transport measures

15. Economic or preferential incentives and disincentives

This measure is aimed at providing the economic or preferential incentives or disincentives for alternate transport modes, destinations, routes or times. The intended impact of this measure is to

encourage the use of alternate modes, destinations, routes and times. The table 1 gives the trip reduction mechanisms with suitable examples to explain the application of the above measure.

	Trip reduction mechanisms	Incentives (Examples)	Disincentives (Examples)
Economic	Alternate modes	Reduced parking costs(HOV)/Free public transport	Increased parking costs (SOV)
	Alternate destinations	Free parking / no toll tax	Parking prohibitions / congestion tax
	Alternate routes	No toll tax	Increased toll tax
	Alternate times	Free or reduced parking costs / No toll tax	Peak-hour increased parking costs / increased toll tax
Preferential	Alternate modes	Bicycle parking facililites / Luggage storage facilities	Parking capacity reduction / parking prohibitions / peripherial parking
	Alternate destinations	Accessibility improvement / better transport facilities	Automobile restricted zones / peripherial parking
	Alternate routes	Differential traffic control schemes	Speed limits
	Alternate times	Differential traffic control schemes	Night time or peak-hour traffic bans

Table B-1: Incentives and disincentives for trip reduction

The description of the examples of trip reduction mechanisms using economic and preferential incentives is given below:

- **Economic incentives and disincentives for alternate mode use**: Economic incentives for alternate mode use are typically provided in the form of reduced parking cost or free parking. The general use of a transport facility can be charged differently for different users. The use of single occupancy vehicles can be discouraged by imposing a different parking cost. This initiative can promote the use of High Occupancy Vehicles (HOV) in many situations. There are multiple ways to encourage a particular mode use. In extreme cases, public transport could be made free to completely avoid the use of private modes.
- **Preferential incentives and disincentives for alternate mode use**: The provision of providing improved transport facilities such as parking, bicycle storage facilities, luggage storage facilities, access improvement to public transport, etc. are common examples of preferential treatment. The principle behind these measures is to improve the services which encourage the use of a particular mode. The development of automobile restricted zones is a good example of disincentives for the car use.
- **Economic incentives and disincentives for alternate destinations**: The use of transport facilities could be differently priced for different destinations in order to influence the destinations.
- **Preferential incentives and disincentives for alternate destinations**: The provision of improved transport facilities such a parking lots, improved accessibility, etc. can be used to influence alternate destinations.
- **Economic incentives and disincentives for alternate routes**: Congestion pricing is an important factor to influence the use of alternate routes.
- **Preferential incentives and disincentives for alternate routes**: The improvements in the rider-ship quality and convenience are preferential incentives for the use of alternate routes.

- **Economic incentives for alternate time**: Parking and other facilities could be differently charged in peak-hours and off-peak hours to encourage or discourage the use of transport facilities at different times.
- **Preferential incentives and disincentives for alternate time**: Banning of vehicles for a particular transport mode is a good example for promoting or demoting the use of transport at different times.

Complimentary measures: Public transport network improvement, Public transport scheduling improvement, Public transport accessibility improvement, Public transport capacity improvement, Special disaster transport services, Public transport right-of-way prioritisation, Public transport information services, Carpooling & other ride sharing programs, Establishment of bicycle-routes & facilities, Establishment of bicycle-routes & facilities, Trip reduction & land-use modification ordinances, Special traffic rules enforcement, Improvement of inter-modal and parking facilities, , Disaster traffic management centre, Work zone coordination & management centre, etc.

16. Trip reduction and land-use modification ordinances

This measure consists of the set of ordinances to reduce the total number of trips by modification or substitution of trips. The implementation of this measure is explained below with examples.

- **Compulsory closing of public and private establishments**: The compulsory closing of dispensable establishments will be implemented as a trip-reduction ordinance. The closing of establishments can be enforced and made mandatory by the State Authorities. The closure includes planned or current events such as games, conferences, conventions, summits, concerts, exhibitions, schools, offices, etc.
- **Alternative or flexible work schedules**: This measure includes office programs or schemes to conduct work on alternate or flexible time basis. The impact of flexible work timings is to reduce the peak hour traffic demand and to distribute the traffic demand into different time frames or periods. These schemes are generally promoted by many offices, schools and other work centres in their work culture. However during disasters, the implementation of these schemes could be made mandatory to allot certain work hours conforming to the disaster operations priority.
- **Certificate scheme**: This scheme is primarily aimed at reducing the number of vehicle trips of disaster tourists, research groups, media groups and other dispensable vehicle trips during or after the disaster outbreak. This scheme will necessitate certain organisations or groups to apply for certificate to conduct their businesses in the disaster affected areas. In this scheme, certificates will be issued only to a few representatives of common business which will result in reduced trips. Differentiated certificate charges calculated by the State authorities will be charged based on type, required time and urgency of work.
- **Inter-operable transport**: This measure refers to changing the use of a particular transport mode for purposes other than its designated use. This measure is aimed at enhancing the transport supply in an event of extreme transport supply deficit for disaster management operations. The change in the designated use of transport such as a use of goods vehicle for passenger transport and vice versa will minimise the transport deficit to a large extent

(e.g. CarGo Tram, Güterstrassen Bahn etc.). This measure will also assist in providing use of empty goods or passenger fleet vehicles for different use. However this measure requires minor changes in design of vehicles to adjust to the new transport use for e.g. vehicle should be equipped with multiple equipments for safety. This measure will integrate multiple operations into few operations through the use of inter-operable transport such as fire control and medical services, fire control and police, etc. This measure will allow similar grouping of tasks for necessary trip reduction and adequate vehicle utilisation. However issues related to inter-operable transport need to be addressed and solved before its implementation.

- **Procurement of company vehicles**: This ordinance will ensure the availability of unused company or government office vehicles for the purposes of transport. A formal agreement could be made between the state transport authorities and respective company vehicle owners to enhance the transport supply in the cases of transport supply deficit for disaster management operations. The process can be initiated during the vehicle registration at state transport authorities. Also such an agreement will provide a complete inventory of company vehicles which may be used during disaster.
- **Trip-chaining programs**: Trip chaining is an act of linking various individual trips into a single multi-purpose trip. The direct benefit of this measure application is the trip reduction amongst other benefits such as reduced fuel costs and time savings. This is mainly aimed at individual motorised transport reduction but it can be used for other transport modes such as public transport, freight transport (city logistics) and even NMT modes when adequate transport arrangements are available to link trips. The following programs are emphasised to encourage the trip-chaining behaviour:
    - The arrangement and allocation of different activity areas for working, shopping & education areas in close proximity to each other promotes the trip-chaining behaviour.
    - The promotion of the use of multi-facility centres or multi-purpose stores support the trip-chaining programs as they tend to provide one-stop shopping.
    - The provision of storage facilities (such as safe lockers) close to the activity areas will enhance the trip-chaining behaviour.
    - The advertisements on information and procedures involved for trip chaining will encourage the road users to combine trips by pre-planning, listing of tasks, grouping of tasks, route selection for multiple purposes, backtracking avoidance, etc.
    - The provision of bus service or another public transport service to link various activity centres and quick transfers (Integrated time scheduling) will promote the trip chaining behaviour in the case of non-car trips.

Land-use modification ordinance is aimed at reducing the number of trips or trip lengths by assigning more appropriate land-use of existing facilities or available spaces. Thus this measure intends to develop land-use modification plans in close cooperation with traffic managers to assist in the disaster response and recovery. The strategic locations can be judiciously used for establishing hospitals, fire stations, flood control, police, etc. at or near the disaster site for the

purposes of traffic management. From the perspective of transport, this measure will also enable the use of facilities such as schools, open stadiums, parks, etc. for the transport purposes to minimise the transport supply deficit that occur during disaster.

Complimentary measures: Public transport network improvement, Public transport scheduling improvement, Public transport accessibility improvement, Public transport capacity improvement, Special disaster transport services, Public transport information services, Carpooling & other ride sharing programs, Establishment of bicycle-routes & facilities, Establishment of bicycle-routes & facilities, Special traffic rules enforcement, Improvement of inter-modal and parking facilities, City logistics system, Household goods delivery transport system, Freight traffic operations control, etc.

17. Road network control

In German cities and it many other European cities, the inter-urban traffic on motorways is controlled through a concept called "**Netzbeeinflussung**" which literally means network influence or control. This measure emphasises on the traffic control which intends to shift traffic to other parts of road network for increasing the traffic safety, improvement of traffic flow conditions, decrease in the environmental impacts and decrease in the trip times resulting less energy costs. The road network control is possible through the implementation of dynamic message signs, access restrictions, parking control systems, and programmable traffic related information. The application of this measure in disasters will assist the road users by providing the route choice. The techniques used for shifting traffic for this measure includes establishment of alternate routes for diversion, contra-flow roads and lane management for disaster traffic routing. This measure will also include techniques which indirectly result in the shift of traffic to other parts of network through traffic restrictions without provision of new routes such as access restrictions, parking control including parking restrictions, ramp metering and control, etc. The following gives the application of road network control during disasters:

- **Diversion routes and special routes establishment**: Traffic routing for disaster traffic involves identification and activation of quickest & safest diversion routes to and from disaster locations. Traffic routing in disasters is mostly an event-dependent routing in which changes of routing are activated by events such as event related congestion or blocked links. The new diversion routes or special routes are identified using learning models. The aim of disaster traffic routing is to provide the separate, non-conflicting routes for evacuation and re-entry of traffic during disaster. The following techniques will be used for disaster traffic routing:
    - **Alternate routes**- In cases where a route choice exist, the traffic will be routed to already available alternate routes (diversion routes). The diversion route may utilise parts of the secondary road network for effective routing.
    - **Contra flow roads**- This technique will be judiciously used in disaster situations requiring evacuation. This involves the assignment of an important road as one-way road in the required direction of evacuation with an aim of optimising the traffic flow during evacuation. The same contra-flow roads can be reversed for re-entry of traffic during the disaster recovery.
    - **Lane management techniques**- Lane management techniques such as reversible flow lanes, turning movement restriction, lane closures, use of shoulder or additional lanes (if available), etc. form a part of effective traffic routing for

evacuation and re-entry of traffic during disaster. This type of traffic routing can significantly improve network resilience by assigning different routes and lanes based on traffic flow conditions.

- **Access restrictions**: This regulation will control traffic by restricting vehicles in certain areas. This may be implemented as a full time restriction or during different time periods of the day or week. The best examples are the day-time entry bans, automobile restricted zones, etc. in urban areas.
- **Parking restrictions**: This regulation will control the designated or undesignated parking spaces in the disaster affected area. The "no parking areas" will be identified and parking restrictions will be imposed. The restrictions may be implemented at current parking and non-parking locations during different time periods of the day or week.
- **Ramp metering and control**: The ramp metering and control will be used to enhance safety by staggering traffic at ramps, closing ramps and diverting traffic to other parts of network. The Ramp meter is a two-phase (red and green, no yellow) traffic light signal that regulates traffic flow entering the freeways according to current traffic conditions of the freeways and ramps. Metering rates can be altered based on freeway traffic conditions. The principle of the ramp metering is to stagger the gathering of vehicles into individual vehicles so that mainstream flow is not interrupted. A ramp meter decides the amount of entry vehicles and their distribution with consideration of real time traffic situation at the ramps and on highways. Three basic applications of this measure are change of metering rates, ramp closures and priority access at ramps.

Complimentary measures: Public transport network improvement, Public transport accessibility improvement, Economic or preferential incentives, Trip reduction & land-use modification ordinances, Road section control, Improvement of inter-modal and parking facilities, Traffic & disaster information service, Disaster traffic management centre, Work- Zone coordination & management centre, City logistics system, Household goods delivery transport system, Freight traffic operations control, etc.

18. Road section control

In German cities including many other European cities, the inter-urban traffic on motorways is controlled through a concept called "Streckenbeeinflussing" which literally means road section influence or control. Unlike road network control, this measure is implemented to control traffic on the motorways without its diversion from the original or intended route. The road section control is possible through the implementation of speed zoning and management, overtaking restrictions, providing accident and congestion warning, providing weather and disaster related information, and the display of other programmable information. The application of road section control is recommended to change the road user behaviour based on the actual driving conditions on a given road section. In disaster situations the techniques which are implemented are lane management and control, speed zoning and management, and use of traffic control devices. The proposed application of road section control for disaster conditions is explained below:

- **Lane management and control**: This sub-measure is a part of inter-urban traffic control to promote the most effective use of available capacity of lanes by re-arranging the lanes. It consists mostly of tidal flow schemes such as reversible flow lanes, turning movement restriction, variable speed limits, lane closures and the use of lanes specifically for high

occupancy vehicles, public transport buses, goods vehicles, etc. It uses the following regulatory techniques for to implement the lane management techniques.

- **Reversible flow lanes**: This technique ensures apportioning of the carriageway between two directions of travel in a manner that matches the volume of traffic. Additional lane(s) can be allotted to the peak flow direction by reducing width of the carriageway meant for the opposite traffic so as to optimise the use of road space. This technique is proved efficient for emergency evacuation purposes (site source).
- **Turning movement restrictions**: This technique minimises the conflicts at intersection by banning of turning movements. It simplifies the traffic signal phases to minimise delays at crowded intersections.
- **Overtaking restrictions**: The regulation controls the driver by prohibiting vehicle overtaking which poses a serious accident threat in bad weather road conditions.
- **Variable speed limits**: The application of different speeds on different lanes manages traffic flow and enhances safety on freeways.
- **Lane closure**: This technique envisages the closure of lane(s) with a view to improving flow by minimising conflicts. Lane control signs, supported by surveillance and detection technologies, allow the temporary or permanent closure of lanes to avoid accident or facilitate the construction along roads.
- **Use of shoulder lanes**: The shoulder lanes can sometimes be used in disaster situations to improve the traffic flow and enhance the road capacity.
- **HOV lanes/Bus lanes/Goods vehicle-only lanes**: The arrangement of lanes can be utilised for HOV, public and freight transport as per traffic requirements.

- **Speed zoning and management**: This sub-measure establishes a safe speed limit for a given section of roadway. Speed management is meant for dissemination of safe speed information to drivers during the disaster traffic conditions. Speed management deals with variable speed limits on different traffic lanes, routes or even traffic network. Speed management is required both for inter-urban and urban traffic control depending on its use. It is also used to route the vehicles of similar speeds to choose respective speed routes. The intended impact of this measure is to enhance the traffic safety by minimising the conflicts between different speed vehicles and improving the traffic flow. The speed management is an important application in accident-prone areas. The traffic control devices used for speed management are static and dynamic message signs showing speed limits. Pre-trip and en-route information also provides the regulation of speed limits.
- **Use of traffic control devices**: The traffic control devices are judiciously applied for the purpose of road section control. The various road signs, signals and markings are implemented for the safe operation of traffic on certain stretches in this type of measure.

Complimentary measures: Special traffic rules enforcement, Trip reduction & land-use modification ordinances, Road network control, Improvement of signalised traffic control, Improvement of non-signalised traffic control, Improvement of inter-modal and parking facilities, Traffic & disaster information service, Disaster traffic management centre, Work- Zone coordination & management centre, etc.

19. Improvement of signalised traffic control

This measure is aimed at improving to signalised traffic control using methods of traffic signal pre-emption and principles of green wave coordination described below:

- **Traffic signal pre-emption**: Traffic signal pre-emption is a system in which the normal operation of traffic lights is pre-empted, often to assist emergency vehicles such as ambulances, fire control vehicles, etc. The most common application of these systems is to allow emergency vehicles priority by changing traffic signals in the path of the vehicle to green (or in some cases, flashing green) and stopping conflicting traffic. The traffic signal pre-emption is also used at railroad grade crossings to prevent collisions, and by light-rail and bus rapid transit systems to allow public transport priority access through intersections to ensure they are able to remain on schedule and improving commute times. The intended impact of the above measure is to reduce the response time for disaster management operations such as emergency vehicles, public transport vehicles, high occupancy vehicles (HOV) and to increase safety. The devices for the traffic signal pre-emption use invisible infrared signals mounted on the vehicles and signal mounted receivers to grant temporarily (pre-empt the normal cycles of traffic lights) the right of way to the vehicles as they approach the intersection.
- **Traffic signal control and coordination**: Traffic signal is a device to control the movements of vehicle at intersections. Traffic signal control systems are interconnected electronic systems that control a network of traffic signals. They typically offer several coordination plans which define the cycle length, phase distributions and offsets for each intersection. In disasters, traffic gating or dispensing systems will be used for protecting certain parts of network form being over-loaded through traffic gating or dispensing systems. The other application of this measure is to coordinate the various signals on a specific route or network by the application of green wave principles of modifying the signal phase timings of every signal in succession based on the prevailing traffic conditions during disasters.

The application of above methods and principles of signalised control will reduce travel time, reduce delay and number of intermittent stops on the route at signals, increase fuel efficiency and reduced emissions, and increase safety for vehicle movements at intersections.

Complimentary measures: Special traffic rules enforcement, Road network control, Improvement of signalised traffic control, Improvement of non-signalised traffic control, Traffic & disaster information service, Disaster traffic management centre, Work- Zone coordination & management centre, etc.

20. Improvement of non-signalised traffic control

This measure uses traffic control devices except traffic signals for controlling traffic. This measure controls traffic by improving the road geometry and by providing driver information through placement of signs, road markings and miscellaneous traffic control devices. It is an important measure for controlling traffic during accidents and incidents, short duration activities like road construction or maintenance and long duration activities like major construction works or maintenance, major special events, major road closures, etc. This measure is aimed at minimising the conflicts between the ordinary traffic and activity-based traffic. It is also important to implement this measure for not only on-road activities but also for off-road activities such as construction of

temporary shelters, quarantine operations, etc. The following gives the brief description of devices used for non-signalised traffic control.

- **Static and dynamic message signs**: Traffic signs are traffic control devices used to warn, regulate and inform drivers. Based on the type of application they are classified as static traffic signs and dynamic message signs. Static message signs provide off-line information whereas dynamic message signs provide information based on real time traffic and weather condition data. Dynamic message signs are also called variable or changeable message signs (VMS, CMS) due to display of varying information. The VMS can be fixed or portable message signs as per the requirements of traffic control. During the non-signalised traffic control, proper attention must be taken to ensure the cancelling of static message signs after their functional use to prevent the dissemination of misleading information. Dynamic message signs are very useful to warn traffic congestion, incidents, work zones or speed limits on a specific roadway element. These are also used for parking guidance and information in urban areas. Truck-mounted, dynamic message signs are sometimes displayed to warn traffic during incidents and accidents where permanent dynamic signs are not available. Trailer-mounted, dynamic message signs are often used to warn, regulate and inform traffic near work zones and for traffic management for predictable events and natural disasters. A complete dynamic message sign should describe a problem statement, location statement, an effect statement and an action statement. The most common use of dynamic message signs is mostly meant for the following purposes:
    - **speed reduction**
    - **overturning restrictions**
    - **warning from risks such as construction, accidents, etc.**
    - **lane closures**
- **Static and Dynamic road markings**: Road markings are the simplest and cost effective measure to regulate, warn or guide traffic through lines, symbols or words. They also serve as symbolic barriers for opposite traffic stream separation, turning movement information, special zones, etc. Road markings are mainly used for central line, traffic lanes, pedestrian crossings, stop lines, no overtaking zones, carriageway width reduction and transition markings, pavement edge lines, route direction arrows, bus stops, parking space limits, yellow box for no-stopping area, etc. Roads markings contribute a lot to road safety by facilitating and alerting the driver to changed road conditions due to accidents, maintenance, construction activities, etc.
- **Miscellaneous traffic control devices**: Most of the traffic control devices such as signs, signals and road markings are supplemented by the following devices for improving traffic flow and enhancing traffic safety:
    - **Barricades**: It is used to warn and alert drivers of hazards created by construction or maintenance activities on or around carriageway.
    - **Traffic cones and bats**: It is a portable temporary device used to delineate the diverted path either around an obstacle or to create additional space for traffic movement.

- **Drums and ropes**: It serves the same function as traffic cones and bats.
- **Box junction**: It is used as a marked area in the form of a box to indicate the area where vehicles must not become stationary even for a short while.
- **Central refuges**: It provides a place of safety for pedestrians from a continuous stream of traffic.
- **Speed breakers**: It is a traffic control device which alerts drivers to the change in driving conditions by reducing the speed of vehicles.
- **Lighted traffic bollards**: It is a lighted device installed on a island to forewarn motorists of the impending obstruction threat.
- **Reflective devices**: It consists of reflective devices placed on road pavement or dividers to warn and guide drivers during the night time.
- **Visibility enhancement devices**: It is a device to enhance the visibility on roads by installing devices such as street lights, strobes, etc.
- **The miscellaneous traffic control devices**: They serve variety of functions and form an essential traffic management measure during construction, maintenance or accident management activities.

Complimentary measures: Special traffic rules enforcement, Road network control, Road section control, Improvement of signalised traffic control, Traffic & disaster information service, Disaster traffic management centre, Work- Zone coordination & management centre, etc.

21. Improvement of inter-modal and parking facilities

This measure focuses on the provision and organisation of inter-modal facilities such as park and ride, kiss and ride, parking facilities, etc. It is aimed at increasing the possibility to use different public transport modes by providing convenient and secured interchange between transport modes such as individual motorised transport, public transport, non motorised transport, etc. and between long- distance and local transport services. The improvements of inter-modal facilities will increase the ride ship of public transport.

Parking is an important but understated issue in disasters. Parking problems in disasters contribute to congestion, accidents, obstruction to disaster control operations and environmental problems. On the other hand parking is an essential requirement for most of urban and non-urban traffic control. Parking management refers to various policies and programs that result in more efficient use of existing parking facilities, improving the services to parking users and improving the parking facility design and location. This measure will include parking restrictions, parking lot closures, parking guidance, priority parking, parking information, establishment of freight-parking zones and free or subsidised parking.

Complimentary measures: Public transport accessibility improvement, Public transport right-of-way prioritisation, Public transport management centre, Establishment of pedestrian routes & facilities, Establishment of bicycle-routes & facilities, Special traffic rules enforcement, Road network control, Traffic & disaster information service, Disaster traffic management centre, Work- Zone coordination & management centre, Freight traffic operations control, etc.

22. Traffic and Disaster information service

In disasters, a range of disaster management activities takes place and as a result traffic conditions vary from time to time. The stakeholders of traffic management and road users demand

consistent, updated, precise and timely information to improve their travel decisions. Therefore, a traffic and disaster-related information service is very necessary. This information service will involve the use of information from various sources such as meteorological departments, traffic control centres, traffic and weather monitoring stations, police and fire departments, disaster management departments, etc. in order to generate traffic and disaster related information. In cases where the traffic and disaster related data is deficient for information purposes, this measure proposes to install traffic and weather monitoring detectors at important locations within the disaster affected region. This multi-sourced data is internally processed for the dissemination of traffic and disaster related information to the public to influence travel decisions before and during the execution of the trip (pre-trip and en-route information). This service includes all processes involved in data collection, processing, storing and information dissemination. This service will benefit various stakeholders of disaster management including traffic management authorities.

This service will provide pre-trip information to influence decisions about the departure time, travel mode; route selection, vehicle type and necessary vehicle improvements, as well as the desired driving behaviour such as safe speed limits and safe vehicle headway. This information will be disseminated through various sources such as internet, conventional public media (radio, TV, newspapers), wireless communications (mobile phones), interactive conventional and wireless phones, traffic information kiosks, public transport terminals, etc.

The service will also provide en-route information about possible diversions, lane closure, warnings, road construction works, location of rest-stations, and real-time weather conditions. The en-route information in intended to change the driving behaviour by providing information on available routes, safe speeds and headways on various road sections, and information of local environment conditions. This information will be disseminated through highway advisory radios, text messages, phones, in vehicle systems, dynamic message signs, warning signs, etc.

Complimentary measures: Public transport information services, Public transport management centre, Special traffic rules enforcement, Economic or preferential incentives , Trip reduction & land-use modification ordinances, Traffic & disaster information service, Disaster traffic management centre, Work- Zone coordination & management centre, etc.

23. Disaster traffic management centre

This measure is aimed at forming the organisation and operational set-up of a disaster traffic management centre at or near the disaster site. In the disaster affected areas, the occurrence of secondary disasters (traffic incidents, traffic accidents, fire, flooding, etc.) is very common and the traffic management issues concerning secondary disasters are inadequately addressed. The functions of this measure are intended to minimise the impacts of secondary disasters on the traffic flow of disaster management traffic. The primary functions of the disaster traffic management centre are:

- **to regulate the traffic flow of incoming and outgoing disaster traffic at or near the disaster site.**
- **to provide traffic management for traffic incidents and accidents at or near the disaster site.**
- **to monitor the traffic and weather conditions at or near the disaster site.**
- **to conduct the collection, dissemination and sharing of the information between disaster management stakeholders.**

- **to provide guidance to the parking for disaster management vehicles at or near the disaster site.**

Based on its functional requirements, the centre can be placed in the desired order of hierarchy of regional traffic management centres. It will be linked with traffic control sub-centres or main traffic management centre, traffic and weather monitoring stations.

Complimentary measures: Public transport information services, Public transport management centre, Special traffic rules enforcement, Economic or preferential incentives , Trip reduction & land-use modification ordinances, Improvement of non-signalised traffic control, Traffic & disaster information service, Disaster traffic management centre, Work- Zone coordination & management centre, etc.

24. Work zone coordination and management centre

This measure focuses on the establishment of the work zone coordination and management centre. The functions of the centre include planning, design and preparation of work zones for traffic control within disaster affected area. The intended impacts of the implementation of this measure are given below:

- **safety of pedestrians, bicyclists and automobile drivers passing through the work zones.**
- **safety of construction and maintenance personnel on the work site from the moving traffic.**
- **improved traffic control for access and exit points at the construction sites to the adjoining properties.**
- **improved traffic management for construction management issues related to work schedules & project delays.**

Response and recovery operations following a disaster normally require a lot of construction, maintenance and repair activities. The traffic generated from such activities demands different types of traffic management which are not included in the daily traffic management. The daily traffic management, more specifically traffic control operations are normally inadequate to manage the incoming and outgoing traffic related to multiple construction sites. Thus the development of work zone management system is necessary for both short-term and long-term activities that generate heavy traffic.

The development of work zone management system consider three aspects which are: (i) the start and end time of activities, (ii) duration of total work and (iii) type of activities involved in the work (construction, repair or maintenance), required by disaster management. This system uses not only regular techniques of traffic control (such as road closures, time restrictions), but also employs modern techniques such as development of stationary and mobile work zones under temporary traffic control. The effectiveness of work zone management increases with enhanced enforcement of traffic regulations for speed & moderate driver behaviour. This measure may also include the traffic management techniques for reducing the time of the construction in the work zones. A proper coordination of work zone management with traffic incident and disaster control centre is necessitated.

Complimentary measures: Public transport accessibility improvement, Public transport capacity improvement, Public transport information services, Public transport management centre, Establishment of pedestrian routes & facilities, Establishment of bicycle-routes & facilities, Special traffic rules enforcement, Economic or preferential incentives , Trip reduction & land-use modification ordinances, Improvement of non-signalised traffic control, Traffic & disaster information service, Disaster traffic management centre, City logistics system, Freight traffic operations control, etc.

Freight transport measures

25. City logistics system

City logistics schemes are relatively new concepts that are aimed at increasing the efficiency of urban freight transport systems as well as reducing traffic congestion and impacts on the environment. This measure refers to the application of logistics concepts for coordinating transport service of different freight origins and destinations through coordinated delivery tours either by linking different freight forwarders (through freight coordination schemes) or via freight distribution centres. This measure includes the identification and establishment of many break-bulk points and consolidation points (freight complexes) for the distribution and aggregation of freight. Urban freight transport is an important issue in disaster management as most of the post-disaster management relies mainly on goods movements. The challenges and problems relating to increasing levels of traffic congestion, traffic safety, environmental impacts and energy consumption during disaster recovery can be better managed through the implementation of city logistics concepts.

Complimentary measures: Trip reduction & Land-use modification ordinances, Improvement of inter-modal and parking facilities, Traffic & disaster information service, Work- Zone coordination & management centre, Household goods delivery transport system, Freight traffic operations control, etc.

26. Household goods delivery transport system

This measure is aimed at reducing the traffic demand generated for consumer shopping. It proposes a system that identifies the consumer household shopping requirements and delivers the household goods directly at consumer's homes. This delivery service would make fewer trips than the individual trips made for the same purpose. The implementation of this measure bears the potential of significantly reducing the total number of city shopping trips. The implementation of this measure would necessitate that a complete delivery transport system be in place; and it can be implemented in a post-disaster recovery period. This system will optimise the goods distribution by linking various destinations of goods demand from houses. In cases where the individual demand for goods distribution cannot be achieved, it will provide ration shops or goods distributions centres in settlements.

Complimentary measures: Trip reduction & Land-use modification ordinances, Improvement of inter-modal and parking facilities, Traffic & disaster information service, Work- Zone coordination & management centre, City logistics system, Freight traffic operations control, etc.

27. Freight traffic operations control

This measure is aimed at controlling the freight traffic in both inter-urban and urban areas. The freight traffic control will based on the freight size, freight route and freight operation time. It is implemented to prohibit dispensable, non-urgent freight traffic on certain roads, to reduce the conflicts between the urgent traffic and non-urgent traffic and to assist the functions of disaster management. This measure also promotes pedestrian-only areas for traffic calming, traffic

segregation for safety, pollution, etc. Freight traffic operation controls are mainly used for traffic segregation based on the principles of segregation including vehicle-vehicle segregation, pedestrian-vehicle segregation and time-segregation of different class of vehicles. Freight traffic operation controls don't apply to disaster-related urgent traffic e.g. ambulances, fire and flood control vehicles, police, press, etc. due to the nature of tasks performed by them. However special attention should be made to overcome the misuse of privileges by certain classes of vehicles. The implementation of this measure (freight traffic operations control) requires installation of traffic signs at major access points and the means of informing traffic. It will also include the allocation and establishment of space for heavy and light trucks, etc. during non-operation periods.

Complimentary measures: Establishment of pedestrian routes & facilities, establishment of bicycle-routes & facilities, Road network control, Road section control, Improvement of Inter-modal and parking facilities, Traffic & Disaster information service, Traffic incident and disaster management centre, Work-zone coordination & management centre, etc.

The questions below contain the text of opinion poll or surveys. These contain questions on traffic management in disasters. Please consider the goals and objectives as given in the questionnaire and indicate your opinion conforming to available goals and objectives. It is assured that your opinion and finally the results will only be used within the purview of this doctoral thesis and information about the interviewee will not be published elsewhere without his or her consent

Part 1: Personal Information

Q.1 Name **Q.3 Professional Degree**

Q.2 Working experience **Years**

Part 2: Ranking Goals

Q.4 How would you rank the goals of traffic management in disasters(from the given goals below)?

Hint : Rank them as 1, 2, 3, 4, with rank (1) given to most important to rank (4) given to the least important

Note : Same rank can also be given to different goals

Traffic management goals in Disasters	Rank	Example
To ensure the quick accesibility & adequate mobility in disasters **(A/M)**		2
To ensure the safety & security of traffic movements in disasters **(S/S)**		3
To ensure the economy of transport system in disasters **(ECO)**		1
To reduce the impact of transport on environment in disasters **(ENV)**		4

Q.5 Please fill the table below by comparing the goal against the goal as per rules indicated. Please use the rank (given by you in above question 4) in the ascending order.

Hint : Use the goals abrv. A/M, S/S,ECO, ENV and sort them in descending order in the table below

Rule : give "0" if the two goals in question are equally important
give "X" if the basic goal is slightly more important than the other goal (in horizontal)
give "XX", if the basic goal is significantly more important than the other goal (in horizontal)
give "XXX" if the basic goal is extremely more important than the other goal (in horizontal)

Note : The above given objectives are not ranked in any order

			Goals			
		abrv.	1	2	3	4
Basic goals	Rank					
	Rank 1		1			
	Rank 2			1		
	Rank 3				1	
	Rank 4					1

Q.6 To achieve the goal of quick accessibility and adequate mobility in Disasters, how would you rank the traffic management objectives given below?

Hint : Rank them as 1, 2, 3, 4, 5, with rank (1) given to most important to rank (5) given to the least important

Note : Same rank can also be given to different objectives

Traffic management accessibility and mobility objectives in Disasters(A/M)	Rank
To provide equitable transport service **(EQUITY)**	
To increase the number of transport route options **(ROUTES)**	
To increase the number of transport mode options **(MODES)**	
To increase the capacity of the transport system **(CAPACITY)**	
To reduce the response time for traffic and other accidents **(RESPONSE)**	

Continued on next page.....

Annexure C: Survey questionnaire for obtaining relative weights of importance

Q.7 Please fill the table below by comparing the goal against the goal as per rules indicated. Please use the rank (given by you in above question 6) in the ascending order.

Hint : Use the abrv. EQUITY, ROUTES, MODES, CAPACITY,RESPONSE and sort them in descending order in the table below

Rule : give "0" if the two goals in question are equally important
give "X" if the basic goal is slightly more important than the other goal (in horizontal)
give "XX", if the basic goal is significantly more important than the other goal (in horizontal)
give "XXX" if the basic goal is extremely more important than the other goal (in horizontal)

Note : The above given objectives are not ranked in any order

			Objectives				
		Objective abrv.	1	2	3	4	5
Basic objectives	Rank						
	Rank 1		1				
	Rank 2			1			
	Rank 3				1		
	Rank 4					1	
	Rank 5						1

Q.8 To achieve the goal of adequate safety and security of transport in Disasters, how would you rank the traffic management objectives given below?

Hint : Rank them as 1, 2, 3, with rank (1) given to most important to rank (3) given to the least important

Note : Same rank can also be given to different objectives

Traffic management safety and security objectives in Disasters(S/S)	Rank
To reduce the response time for traffic and other accidents **(RESPONSE)**	
To reduce the number of traffic accidents **(FREQ)**	
To reduce the severity of traffic accidents **(SEV)**	

Q.9 Please fill the table below by comparing the goal against the goal as per rules indicated. Please use the rank (given by you in above question 8) in the ascending order.

Hint : Use the abrv. RESPONSE, FREQ, SEV and sort them in descending order in the table below

Rule : give "0" if the two goals in question are equally important
give "X" if the basic goal is slightly more important than the other goal (in horizontal)
give "XX", if the basic goal is significantly more important than the other goal (in horizontal)
give "XXX" if the basic goal is extremely more important than the other goal (in horizontal)

Note : The above given objectives are not ranked in any order

			Objectives		
		Objective abrv.	1	2	3
Basic objectives	Rank				
	Rank 1		1		
	Rank 2			1	
	Rank 3				1

Q.10 To achieve the goal of economy in Disasters, how would you rank the traffic management objectives given below?

Hint : Rank them as 1, 2, with rank (1) given to most important to rank (2) given to the least important

Note : Same rank can also be given to different objectives

Traffic management economy objectives in Disasters(ECO)	Rank
To reduce the total transport costs **(TCOST)**	
To maximise the economic efficiency **(ECO_EFF)**	

Continued on next page.....

Annexure C: Survey questionnaire for obtaining relative weights of importance

Q.11 Please fill the table below by comparing the goal against the goal as per rules indicated. Please use the rank (given by you in above question 10) in the ascending order.

Hint : Use the abrv. TCOST,ECO_EFF and sort them in descending order in the table below

Rule : give "0" if the two goals in question are equally important
give "X" if the basic goal is slightly more important than the other goal (in horizontal)
give "XX", if the basic goal is significantly more important than the other goal (in horizontal)
give "XXX" if the basic goal is extremely more important than the other goal (in horizontal)

Note : The above given objectives are not ranked in any order

			Objectives	
		Objective abrv.	1	2
Basic objectives	Rank			
	Rank 1		1	
	Rank 2			1

Q.12 To achieve the goal of reducing the environmental impact of transport in Disasters, how would you rank the traffic management objectives given below?

Hint : Rank them as 1, 2, 3, with rank (1) given to most important to rank (3) given to the least important

Note : Same rank can also be given to different objectives

Traffic management environment objectives in Disasters(ENV)	Rank
To minimise the consumption of energy resources **(ENER)**	
To reduce the air pollution related to transport **(AIR)**	
To reduce the noise pollution related to transport **(NOISE)**	

Q.13 Please fill the table below by comparing the goal against the goal as per rules indicated. Please use the rank (given by you in above question 12) in the ascending order.

Hint : Use the abrv. ENER, AIR, NOISE and sort them in descending order in the table below

Rule : give "0" if the two goals in question are equally important
give "X" if the basic goal is slightly more important than the other goal (in horizontal)
give "XX", if the basic goal is significantly more important than the other goal (in horizontal)
give "XXX" if the basic goal is extremely more important than the other goal (in horizontal)

Note : The above given objectives are not ranked in any order

			Objectives		
		Objective abrv.	1	2	3
Basic objectives	Rank				
	Rank 1		1		
	Rank 2			1	
	Rank 3				1

Annexure C: Survey questionnaire for obtaining relative weights of importance

Part 3: Implementation Difficulties

Q.14 Consider in cases of disasters, How would you rank the difficulties of barriers in implementation of traffic management measures in disasters (from the given difficulty criteria below)?

Hint : Rank them as 1, 2, 3, 4, with rank (1) given to most difficult to rank (4) given to the least difficult

Note : Same rank can also be given to different difficulties

Difficulty criteria	Rank	Example
Required cost (MCOST)		2
Required technical systems (TECH)		3
Required institutional participation (INST)		4
Required public acceptance (ACCEPT)		1

Q.15 Please fill the table below by comparing one difficulty criterion against the other difficulty criterion as per rules indicated. Please use the rank (given by you for above question 14) in the descending order of difficulty criteria.

Hint : Use the difficulties abrv. MCOST, TECH, INST, ACCEPT and sort them in descending order in the table below

Rule : give "0" if the two difficulties in question are equally difficult
give "X" if one difficulty is slightly more difficult than the other difficulty (in horizontal)
give "XX", if one difficulty is significantly more difficult than the other difficulty (in horizontal)
give "XXX" if one difficulty is extremely more difficult than the other difficulty (in horizontal)

Note : The above given difficulties are not ranked in any order, please choose your own ranking order

			Difficulty criteria			
		abrv.	1	2	3	4
Difficulty criteria	Rank					
	Rank 1		1			
	Rank 2			1		
	Rank 3				1	
	Rank 4					1

Q.16 To implement traffic management measures in disasters, which type of cost is more difficult to finance than the other?

Hint : Rank them as 1 or 2, 1 being more difficult and 2 being less difficult

Note : Same rank can also be given to different difficulties

Sub-criteria	Rank
Investment cost (INV_COST)	
Operation and maintenance cost (O&M_COST)	

Q.17 Please fill the table below by comparing one difficulty criterion against the other difficulty criterion as per rules indicated. Please use the rank (given by you for above question 16) in the descending order of difficulty criteria.

Hint : Use the difficulties abrv. INV_COST, O&M_COST and sort them in descending order in the table below

Rule : give "0" if the two difficulties in question are equally difficult
give "X" if one difficulty is slightly more difficult than the other difficulty (in horizontal)
give "XX", if one difficulty is significantly more difficult than the other difficulty (in horizontal)
give "XXX" if one difficulty is extremely more difficult than the other difficulty (in horizontal)

Note : The above given difficulties are not ranked in any order, please choose your own ranking order

Continued on next page.....

Annexure C: Survey questionnaire for obtaining relative weights of importance

			sub-criteria	
		Difficulty abrv.	1	2
sub-criteria	Rank			
	Rank 1		1	
	Rank 2			1

Q.18 To implement traffic management measures in disasters, which type of technical systems are more difficult to apply than the other?

Hint : Rank them as 1 or 2, 1 being more difficult and 2 being less difficult

Note : Same rank can also be given to different difficulties

Sub-criteria	Rank
Operation and control systems (O&C)	
Information systems (IS)	

Q.19 Please fill the table below by comparing one difficulty criterion against the other difficulty criterion as per rules indicated. Please use the rank (given by you for above question 18) in the descending order of difficulty criteria.

Hint : Use the abrv. O&C, IS and sort them in descending order in the table below

Rule : give "0" if the two difficulties in question are equally difficult
give "X" if one difficulty is slightly more difficult than the other difficulty (in horizontal)
give "XX", if one difficulty is significantly more difficult than the other difficulty (in horizontal)
give "XXX" if one difficulty is extremely more difficult than the other difficulty (in horizontal)

Note : The above given difficulties are not ranked in any order, please choose your own ranking order

			sub-criteria	
		Difficulty abrv.	1	2
sub-criteria	Rank			
	Rank 1		1	
	Rank 2			1

Q.20 To implement traffic management measures in disasters, which institution participation is more difficult than the other?

Hint : Rank them as 1 or 2, 1 being more difficult and 2 being less difficult

Note : Same rank can also be given to different difficulties

Sub-criteria	Rank
Political bodies (city, regional, national)(POL)	
Transport related institions (transport authorities, operators)(TRANS)	

Q.21 Please fill the table below by comparing one difficulty criterion against the other difficulty criterion as per rules indicated. Please use the rank (given by you for above question 20) in the descending order of difficulty criteria.

Hint : Use the abrv. POL, TRANS and sort them in descending order in the table below

Continued on next page.....

Annexure C: Survey questionnaire for obtaining relative weights of importance

Rule : give "0" if the two difficulties in question are equally difficult
give "X" if one difficulty is slightly more difficult than the other difficulty (in horizontal)
give "XX", if one difficulty is significantly more difficult than the other difficulty (in horizontal)
give "XXX" if one difficulty is extremely more difficult than the other difficulty (in horizontal)
Note : The above given criteria are not ranked in any order

			sub-criteria	
		Difficulty abrv.	1	2
sub-criteria	Rank			
	Rank 1		1	
	Rank 2			1

Q.22 To implement traffic management measures in disasters, whose public acceptance is more difficult than the other?

Hint : Rank them as 1 or 2, 1 being more difficult and 2 being less difficult
Note : Same rank can also be given to different difficulties

Sub-criteria	Rank
Transport users (pedestrians, bicyclists, drivers) (T_USER)	
Non transport users (residents, vehicle manifacturer) (NT_USER)	

Q.23 Please fill the table below by comparing one difficulty criterion against the other difficulty criterion as per rules indicated. Please use the rank (given by you for above question 22) in the descending order of difficulty criteria.

Hint : Use the abrv. T_USER, NT_USER and sort them in descending order in the table below
Rule : give "0" if the two difficulties in question are equally difficult
give "X" if one difficulty is slightly more difficult than the other difficulty (in horizontal)
give "XX", if one difficulty is significantly more difficult than the other difficulty (in horizontal)
give "XXX" if one difficulty is extremely more difficult than the other difficulty (in horizontal)
Note : The above given sub-criteria are not ranked in any order

			sub-criteria	
		Difficulty abrv.	1	2
sub-criteria	Rank			
	Rank 1		1	
	Rank 2			1

Thank you very much for your cooperation

Annexure C: Survey questionnaire for obtaining relative weights of importance

Annexure D: An example of rating the TM measures

			PT								NMT			IMT					MIM										FR		
			1	2	3	4	5	6	7	8	1	2		1	2	3	4		1	2	3	4	5	6	7	8	9	10		1	2	3
		Public Transport Measures	Public Transport Network Improvement	Public Transport Scheduling Improvement	Public Transport Accessibility Improvement	Public Transport Capacity Improvement	Special Disaster Transport Services	Public Transport Right-of-Way Prioritisation	Public Transport Information Services	Public Transport Management Centre	Non-Motorised Transport Measures	Establishment of Pedestrian routes & Facilitie	Establishment of Bicycle-routes & Facilities	Individual Motorised Vehicle Measures	Carpooling & other Ride Sharing Programs	Car Rental Services	Automobile Roadway Repair Service	Special Traffic Rules Enforcement	Multimodal and Intermodal Transport Measur	Economic or Preferential Incentives	Trip reduction & Land-use Modification Ordi	Road Network Control	Road Section Control	Improvement of Signalised Traffic Control	Improvement of Non-signalised Traffic Contr	Improvement of Inter-modal and Parking Fac	Traffic & Disaster Information Service	Disaster Traffic Management Centre	Work- Zone Coordination & Management Ce	Freight Transport Measures	City Logistics System	Household Goods Delivery Transport Syster	Freight Traffic Operations Control
	Effectiveness assessment																															
	(A/M)																															
0,38	*1.1 To provide equitable transport service* ***(EQUITY)***	0,28	3	3	3	3	3	1	3	3		3	3		3	3	1	3		3	0	0	0	0	0	2	3	3	3		3	3	0
	1.2 To increase the number of transport route options ***(ROUTES)***	0,23	3	2	3	0	3	0	2	3		3	3		0	0	0	0		1	1	3	3	2	2	0	3	3	3		3	1	3
	1.3 To increase the number of transport mode options **(MODES)**	0,22	3	3	3	3	3	0	2	3		3	3		3	3	1	3		1	1	0	0	0	0	2	3	3	3		3	3	0
	1.4 To increase the capacity of the transport system **(CAPACITY)**	0,27	2	3	3	3	3	3	3	3		2	2		3	3	3	3		2	1	3	3	3	3	2	2	3	3		3	3	0
	Goal 2:To ensure the safety & security of traffic movements in disasters (S/S)	1,00																														
0,30	*2.1 To reduce the response time for traffic and other accidents* ***(RESPONSE)***	0,33	1	1	1	1	1	3	3	3		1	1		0	0	3	3		1	2	3	3	3	3	0	3	3	3		0	0	3
	2.2 To reduce the number of traffic accidents ***(FREQ)***	0,38	3	3	3	3	1	3	3	3		3	3		0	0	2	3		1	2	3	3	1	3	1	3	3	3		2	3	3
	2.3 To reduce the severity of traffic accidents ***(SEV)***	0,29	3	3	3	3	2	3	2	3		3	3		0	0	2	3		1	1	3	3	1	3	1	2	2	3		2	3	3
	Goal 3:To ensure the economy of transport system in disasters (ECO)	1,00																														
0,19	*3.1 To reduce the total transport costs* ***(TCOST)***	0,49	3	3	3	3	0	3	1	3		3	3		2	0	1	0		3	3	2	2	2	2	1	3	3	3		3	3	2
	3.2 To maximise the economic efficiency ***(ECO_EFF)***	0,51	3	3	3	3	1	2	2	3		3	3		2	0	1	3		1	3	2	2	2	2	2	3	3	3		3	3	2
	Goal 4:To reduce the impact of transport on environment in disasters (ENV)	1,00																														
0,13	*4.1 To minimise the consumption of energy resources* ***(ENER)***	0,38	3	2	2	3	1	3	1	3		3	3		2	0	1	2		2	3	1	1	1	1	2	2	2	2		2	2	2
	4.2 To reduce the air pollution related to transport ***(AIR)***	0,36	2	2	2	3	1	1	1	3		3	3		2	0	1	2		2	3	1	1	1	1	2	2	2	2		2	2	2
	4.3 To reduce the noise pollution related to transport ***(NOISE)***	0,26	2	2	2	3	1	1	1	3		3	3		2	0	1	2		2	3	1	1	1	1	2	2	2	2		2	2	2
		1,00																														
	Applicability assessment																															
	Criteria 1:Required cost (MCOST)																															
0,31	*1.1 Investment cost (INV_COST)*	0,57	2	3	3	3	3	3	2	2		1	1		1	1	1	2		1	1	3	3	1	2	2	3	3	3		3	1	1
	1.2 Operation and maintenance cost (O&M_COST)	0,43	1	3	3	1	2	1	2	3		1	1		1	1	2	1		3	1	3	3	1	1	1	3	3	3		2	1	1
	Criteria 2:Required technical systems (TECH)	1,00																														
0,27	*2.1 Operation and control systems (O&C)*	0,60	1	1	1	1	1	2	1	3		2	2		0	0	2	2		0	0	3	3	1	1	1	3	3	2		0	0	1
	2.2 Information systems (IS)	0,40	1	1	1	1	1	1	3	3		1	1		1	1	1	1		1	2	3	3	1	1	1	3	3	2		1	1	2
	Criteria 3:Required institutional participation (INST)	1,00																														
0,24	*3.1 Political bodies (city, regional, national)(POL)*	0,59	1	0	1	0	2	2	1	2		1	1		0	0	0	2		3	3	1	1	0	1	1	1	2	2		3	0	1
	3.2 Transport related institions (transport authorities, operators)(TRANS)	0,41	2	2	2	1	2	1	2	2		1	2		1	1	1	2		3	2	3	3	0	1	2	3	3	3		3	1	1
	Criteria 4:Required public acceptance (ACCEPT)	1,00																														
0,18	*4.1 Transport users (pedestrians, bicyclists, drivers) (T_USER)*	0,47	1	1	1	0	0	1	0	0		1	1		1	1	1	3		0	3	1	1	0	0	0	0	0	0		1	0	1
	4.2 Non transport users (residents, vehicle manifacturer, operators) (NT_USER)	0,53	1	1	1	1	1	1	0	0		0	0		1	1	1	3		1	1	0	0	0	0	0	0	0	0		0	0	2
		1,00																														

- The **Analytic Hierarchy Process (AHP)** is a mathematical technique for multi-criteria decision making developed by Saaty. It enables people to make decisions involving many kinds of concerns including planning, setting priorities, selecting the best among a number of alternatives, and allocating resources.
- It stresses the importance of intuitive judgement of decision makers as well as the consistency of comparison of alternatives in the decision making process.

Steps developed by Saaty in applying AHP

- Define the problem and determine its goal
- Construct pair-wise matrix (size n X n).
- Compare in pair wise fashion the relative importance of each of the alternative, in the vertical side, with respect to the alternative on horizontal side. For each pair of judgement the decision maker specifies a judgement about how much more important one attribute is than other.
- There are three types of approaches for specifying pair-wise comparison: numerical, graphical and verbally mediated. Each method requires the decision maker to know how much more, “attribute x is desirable than attribute y”.
- For a numerical approach the decision maker answers each question with a number, for example, “attribute x is 3 times more desirable than attribute y”
- Hierarchical synthesis is used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries.
- For graphically mediated judgements available software can be used.
- For verbally mediated judgements, decision maker answers each question with a verbal expression from Table: Numerical Scales.

VERBAL EXPRESSION	NUMERICAL COUNTERPART
Equal Importance/ Equal desirability of alternatives	1
Moderate importance of one attribute over another/ Moderate desirability of one alternative over another	3
Strong importance of one attribute over another/Strong desirability of one alternative over another.	5
Very strong importance of one attribute over another/Very strong desirability of one alternative over another.	7
Extreme importance of one attribute over another/ Extreme desirability of one alternative over another.	9

Table: Numerical Scales

- If 1 is moderately more desirable than alternative 2, then this table can be used.

- Reciprocals are automatically assigned in each pair-wise comparison.
- The procedure is repeated for each set of attributes in the hierarchy. Thereafter the final overall desirability score for each of the alternatives is computed is computed
- It is important to note that all diagonal members of the MPC will always be equal to 1.
- The vector weights of each MPC are obtained using the principal eigenvector method. The principal eigenvector e* which solves the following equation, where M is the MPC of interest and μ max is the principal eigenvector of the matrix .
- e* can also be found out as the nth root of the product of the numbers in the row.
- Normalise the Eigenvector so that its elements sum up to 1.00. To solve for the normalized principal eigenvector p divide each of the n elements of the principal eigenvector e* by the sum of the elements e*.
- P = (1/ ∑ ei) e*
- In AHP, before computing the weights based on pair-wise judgments, the degree of consistency is measured by the Consistency Index. Perfect consistency implies a value of zero. However, perfect consistency cannot be demanded since, as human beings, we are often biased and inconsistent in our subjective judgments. Therefore, it is considered acceptable if consistency index ≤ 0.1. For values greater than 0.1, the pair-wise judgments may be revised before the weights are computed.
- The consistency is determined by using Eigen value, μmax, to calculate consistency index, CI as follows
- CI = (μ max -n) / (n-1) where n is the matrix size.
- Consistency ratio = C.I /RCN.
- RCN , random consistency number, for various order of matrix is given in the Table: Random Consistency Numbers. The consistency ratio represents the error in the consistency of the paired comparison done in a matrix.

ORDER OF MATRIX "n x n"	RANDOM CONSISTENCY NUMBER
1	0.00
2	0.00
3	0.53
4	0.90
5	1.12
6	1.24
7	1.32

8	1.41
9	1.45
10	1.47
11	1.49
12	1.51
13	1.56
14	1.57
15	1.59

Table: Random Consistency Numbers

Annexure D: Explanation of AHP Technique

Annexure E: Scenario Description of Tsunami Disaster

Main Highlights

Disaster type	Earthquake under the sea bed causing Tsunami waves affecting Indian Subcontinent
Location	Nagapattinam, Tamil Nadu, South India
Causalities	4592 deaths, 40929 affected population
Infrastructure damage	Substantial infrastructure damage
Evacuation	People homeless, people at potential risk
Secondary disasters	Fire hazards

Scenario Overview

General description

The devastating tidal waves affected 13 coastal districts of Tamil Nadu State of India throughout the entire coast line of 187.9 km causing 6069 reported deaths and affecting 176184 people. The study however focuses on Nagapattinam municipal council which reported 4592 reported deaths in the district in a thin 10 km stretch in the town.

Transport supply condition

The tsunami waves caused damaged to the entire 10 km stretch of the town from the waves entering 1.5 km inside the town. The roads and terminals were flooded with water and debris on road made the transport of people challenging. The communication and electricity supply were cut off in the affected areas causing the traffic signal control and traffic information dissemination impossible.

Vehicles in the town experienced major breakdowns due to water flow in the engine and other machine parts giving rise to reduction in the individual motorised transport and vehicle performance. The vehicle traction, vehicle stability and vehicle manoeuvrability resulted in poor vehicle performance in the affected areas.

The transport user reported difficulties of poor selection of route, speed, time and destination resulting in poor traffic flow and increased traffic violations due to panic and confusion. The transport operators experienced difficulties due to poor transport operations and management.

Transport demand condition

The sudden outbreak of the disaster provided no warning time for the preparedness of disaster response. It resulted in the random order of disaster operations lacking priority, sequence and scheduling. The transport demand increased many fold due to sudden mobilization of multiple disaster support functions. The first few days accounted to DSF's such as disaster control (search and rescue of tsunami victims), medical care, food and water supply, public works and engineering (temporary construction and repair) and housing. The disaster resulted in moderate disaster response time of 30 days and disaster recovery is still in progress. The segregation of activities of disaster response resulted in multiple origins and destinations as a result of which traffic management became a difficult task.

Development States of Nagapattinam

Social development state

The total of 3.5 % population is challenged mobility challenged due to physical, education and personal disabilities. It includes population such as deaf, blind, dumb, physically challenged, mentally challenged, disabled literacy population etc. This accounts to more than 40,000 people with disabilities excluding groups such as children, old people, people with illnesses, medication etc in the district. The 10 % of the mobility challenged people is assumed to be affected during Tsunami disaster. Thus there was a great need to provide transportation needs for mobility challenged people.

Technological development state

The most of roads are undivided 2 lane carriageway, asphalt roads in poor conditions. There are no national highways passing through the district.

The traffic control is predominantly done manually by the traffic police department. The district has very few traffic signals used for traffic control which results in poor traffic flow conditions and accidents.

The public transport is a most common in general population and two-wheeler ownership is very high among middle and high income groups. The public transport is mostly dominated by buses with passenger capacity of 60 passengers, although high vehicle occupancy is observed even in low capacity buses. The buses are mostly diesel engines in poor maintenance due to age and condition. The fleet breakdown rate is very high among public transport. The car ownership is still low in high income groups and is limited to high income groups only. The cars are mostly diesel based cars and the two-wheelers are mostly four-stroke which high energy efficiency.

Environmental development state

Apparently the region does not have much variation in topography. The basic slope is from west to east towards the sea. The elevation of almost entire district is 0-15m the town is located at a height of about 5 meters above sea level. The villages have a uniform topography with a slight slope towards the sea i.e. east. The environmental development state does not pose any risk transport development in the district due to uniform topography and good environmental conditions.

The climate of this region is ‘warm-humid’ climate. Rainfall ranges from a minimum of 50 mm to a maximum of 110 mm. Rainy season is from June to November and hot weather persists for three months during March, April and May. The high rainfall that persists for 6 months increases the transport infrastructure maintenance costs.

Air quality status is well within the limits as per air quality standards but the noise levels are high in the urban areas of the district.

Built-environmental state

The overall density of the district has increased to 770 persons/sq.km. The population density in rural and urban areas is 600 persons/sq.km and 3456 persons/ sq.km respectively.

The proportion of urban population to total population has increased to about 26.79% exhibiting high urbanization levels. The high rate and urbanization level has resulted in the concentration of activities posing problems of traffic management in urban centers.

Economy development state

There is a steady increase in the per capita income of the state and accordingly the people have more disposable income.

The gross state domestic product of Tamil Nadu state is over 8% at current prices. The transport sector fall under tertiary sector and expenditure on transport is more than 4% of the overall state domestic product.

The Gross domestic product of India is over 8 % with significant expenditure on transport infrastructure development.

Political and administrative development state

Expenditure on disaster management indicates the interests of politics in disaster management.

The present government is quite stable in the office with the total time spent

Poor coordination between different stakeholders is observed among the disaster management.

The traffic laws pertaining to safety helmets, lane driving, speed controls etc. are not enforced fully and such attitudes have changed the driving conditions on urban roads in the district that pose a major threat to the safety of transport users and non-users.

Transport resource utilisation

The multiplicity of factors contributes to the poor transport resource utilization in tsunami affected areas. The district has a total length of 358.50 kms of major district roads and 87.28 kms of other district roads. The villages are connected either through surface or other roads. For every 1000 population, the length of road is just above 1 Km as against 2.2 Km. per 1000 population in the state.

The data on Fleet utilization, Capacity utilization, and Human skills utilization is not available.

Transport resource information

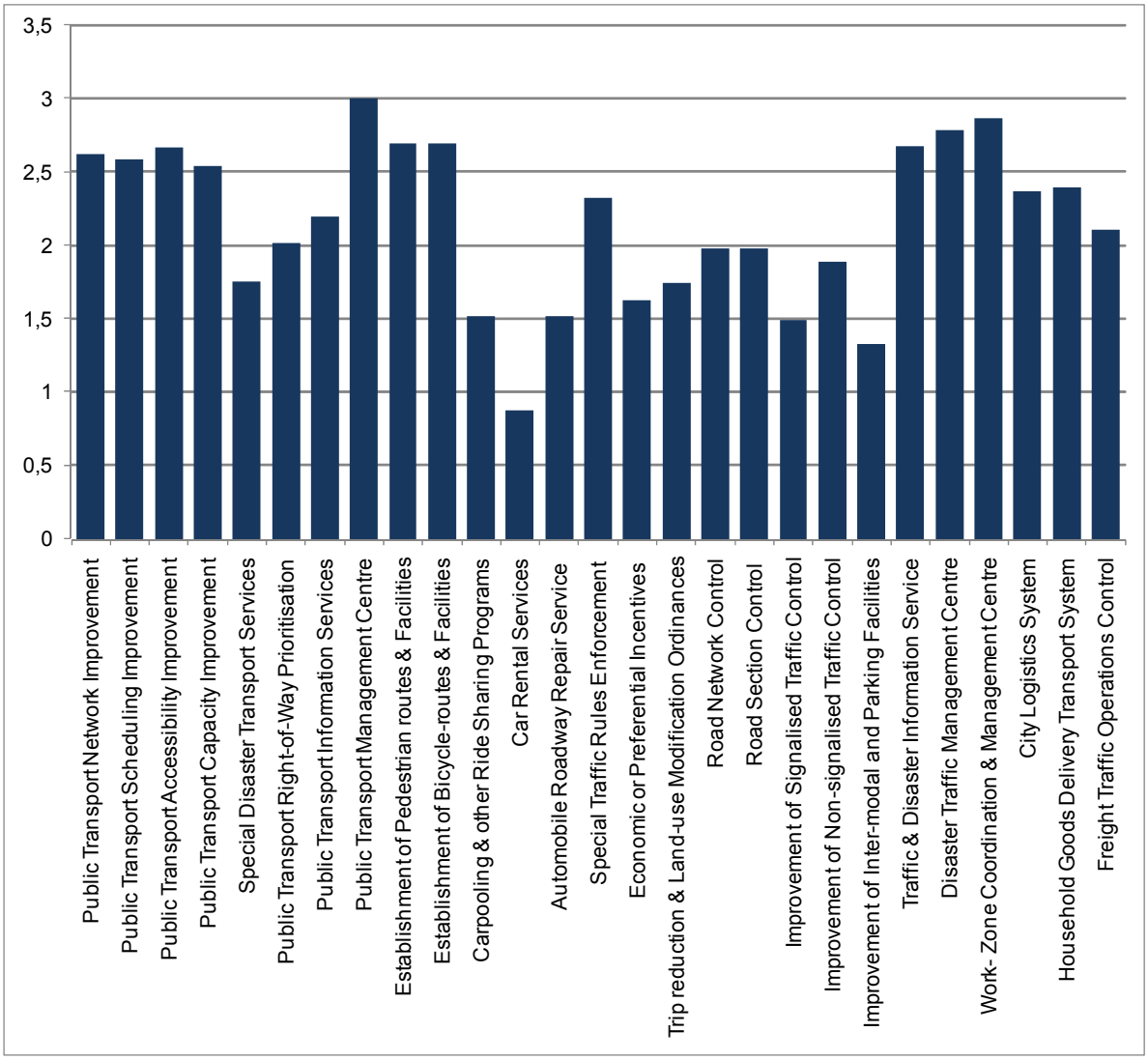
The poor warning and post-tsunami information caused poor traffic information to the transport users and non-users. There was no or little information on transport routes, schedules, transport destinations, transport services availability etc. to aid the mobility in disasters. Further the unavailability of standard operating procedures, disaster management framework resulted in the poor coordination amongst the transport operators in the district.

Transport resource scheduling

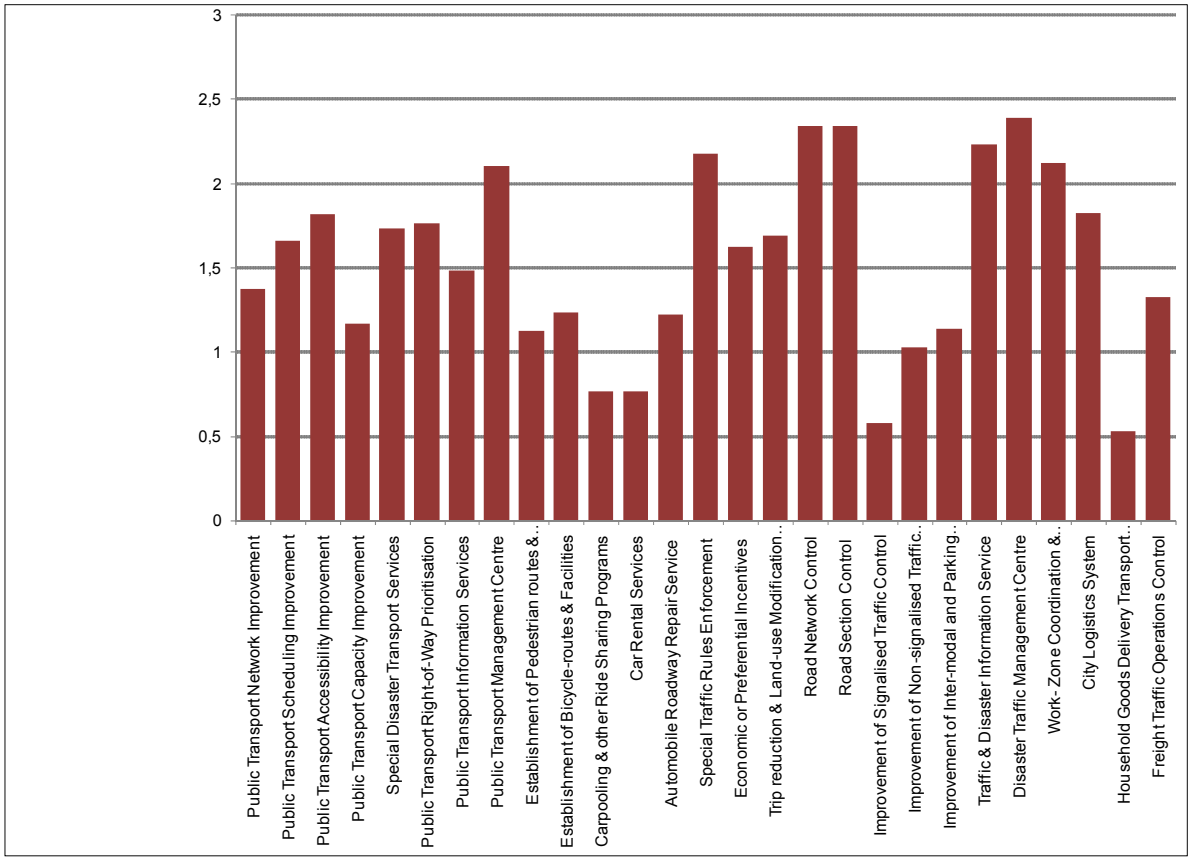
The transport encountered poor transport resource scheduling after the impact of Tsunami. The transport service regularity is seriously hampered due to deficit in the transport supply. The transport service punctuality was not adequately maintained to get the benefits of transport connectivity with the other transport services. The reasons of poor service punctuality are mainly the poor road condition, poor transport information, poor vehicle condition including vehicle breakdowns, poor weather condition etc. The unavailability of fixed routes also contributed to punctuality or multi-modal connectivity problems. The unavailability of vehicle roaster plan also contributed to scheduling problems in tsunami. The absence of implementation of traffic segregation principles specially based on time resulted in poor traffic flow conditions owing to heterogeneity of traffic.

Most difficult	Road Network Control Road Section Control	Public Transport Management Centre Work- Zone Coordination & Management Centre Special Traffic Rules Enforcement Traffic & Disaster Information Service Disaster Traffic Management Centre
Moderately difficult	Economic or Preferential Incentives Trip reduction & Land-use Modification Ordinances Special Disaster Transport Services	Public Transport Scheduling Improvement Public Transport Right-of-Way Prioritisation Public Transport Accessibility Improvement City Logistics System
Least difficult	Car Rental Services Improvement of Inter-modal and Parking Facilities Improvement of Signalised Traffic Control Automobile Roadway Repair Service Carpooling & other Ride Sharing Programs Improvement of Non-signalised Traffic Control	Household Goods Delivery Transport System Establishment of Pedestrian routes & Facilities Public Transport Capacity Improvement Establishment of Bicycle-routes & Facilities Freight Traffic Operations Control Public Transport Network Improvement Public Transport Information Services

Annexure F: Priority classes of TM measures



Annexure G: Effectiveness of selected TM measures



Annexure H: Difficulties of selected TM measures

Annexure I: Application of proposed measures in Delhi

Introduction

Delhi is politically and economically one of the most important States of India. Its ability to disaster management is of critical significance. Disaster is extremely prone and vulnerable to natural and manmade disasters. The whole region of Delhi falls under Seismic Zone IV, at very high risk to earthquakes (Vulnerability Atlas of India, 1997). Previous occurrences of Earthquakes reveal high intensity ranging from M 5.5 to 6.7 based on Richter scale. Delhi has more than 60% area under unauthorised colonies and urban slums which compound the vulnerabilities to disasters. Risks of occurrences of terrorist attacks, fires, industrial and chemical disasters also exist. Another rational to intensify efforts of disaster management including traffic management is the minimisation of disaster-incurred losses which reduces the decades of development in the affected area.

In this section the key proposals for the implementation of the formulated traffic management strategies and measures will be discussed. The strategies application is discussed for the capital city of India, New Delhi. This chapter envisages the present developments of transport in Delhi and proposes the application of the formulated strategies (Chapter 8). The shortcomings in strategies application due to application requirements and exiting transport development state are presented in the next chapter. The proposals to minimise the issues related to implementation are also presented.

Overview

New Delhi is located at 28°40' N, 77°13' E in the northern India. The Delhi city borders the Indian states of Uttar Pradesh on East and Haryana on West, North and South. National Capital Territory (NCT) of Delhi is divided into nine districts, which are shown in the figure. River Yamuna divides Delhi and on the east of the river are East and North East districts. According to the 2001 Census of India, the population of Delhi in the same year was 13,782,976. Some literature estimates the population more than 16 million in year 2008. Everyday more than 500,000 people commute from other cities of India to Delhi (floating population).

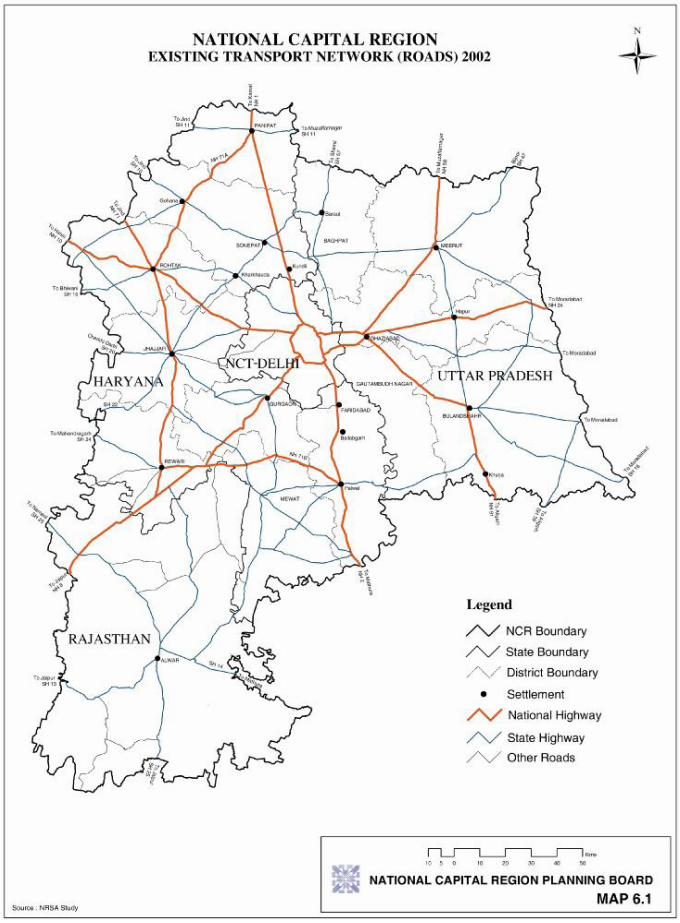
Districts of National Capital Territory of Delhi

The population density of Delhi was 9,294 people per square kilometres in year 2001, with a sex ratio of 821 women per 1000 men. East and North East districts of Delhi have highest population

densities of 22,368 persons/km² and 29,397 persons/km². The resulting high migration rate made Delhi as one of fastest growing metropolis in the world. Literacy rate of Delhi is more than 81 %.

The National Capital Territory of Delhi is spread over an area of 1,483 km² (573 sq mi), of which 591.01 km² (302 sq mi) is designated rural, and 891.09 km² (270 sq mi) urban. National Capital Territory of Delhi has a maximum length of 51.9 km (32 mi) and the maximum width of 48.48 km (30 mi). There are three local bodies (statutory towns) namely, Municipal Corporation of Delhi (area is 1,397.3 km² (540 sq mi)), New Delhi Municipal Committee (42.7 km² (16 sq mi)) and Delhi Cantonment Board (43 km² (17 sq mi).

In Delhi, the road infrastructure is maintained by Public Works Department (PWD), New Delhi Municipal Committee (NDMC), Municipal Corporation of Delhi (MCD), Delhi Contentment board and Delhi Development Authority. The respective organisations are responsible for the construction and maintenance of their roads. The road network of Delhi is ring and radial system, with outer and inner ring roads. The area of roads in Delhi is over 21% of total land compared to 6.5 % in Kolkata and 8% in Mumbai. However the total number of registered vehicles in Delhi (0.5 million) is more than the sum of vehicles in Kolkata, Mumbai and Chennai. Inner ring road is the arterial of Delhi transport system. This is about 51 km long with six-lane divided carriageway having more than 270 km lane length and it runs through the heart of the city. In addition, 45km long service road also exists along Ring Road with equivalent of 90 km lane length. Thus total lane length of Ring Road inclusive of service road is 358 lane-km. It is the busiest road and carries the maximum volume of traffic. All the five National Highways passing through Delhi namely, NH-I, NH-2, NH-8, NH-10 & NH-24 start from this road.



System of roads in National Capital Region

Outer ring road is the second important road carrying heavy traffic in most of its length of 27.30 km. The lane-km length of outer ring road 163.80 km & service road 63.6 km

The public transport of Delhi is largely dependent on road transport. The public transport is primarily operated on buses which have a largest fleet of Compressed Natural Gas (CNG) in the world (3106 CNG buses) operated on more than 700 routes. Furthermore there are three inter-state bus terminals which cater to inter-state bus services by state transport corporations and several private operators.

Recently, a bus rapid transit corridor is developed and operated for a length of 5.8 km. The eleventh five-year plan (2007-2012) proposes a length of 103 km on seven corridors from a total of 26 corridors for the operation of high capacity bus system (HCBS).

The Delhi mass rapid transit system is known as Delhi Metro. As of June, 2008 the total network length of Delhi Metro is 68.2 km. There are expansion plans to increase the total length of Delhi Metro network to 190 km by Oct, 2010 and a total of 413.76 km (including NCR towns) by year 2021. Currently, the traffic demand served by Delhi metro is only 1% of the total traffic demand.

The three-wheeler Auto-rickshaws are popular mode of public transport in Delhi. The taxis are not common mode of public transport among common public due to high per-kilometre fares. Recently on-call radio-taxi service is introduced to fulfil the demand of customers on need basis. The pedal-powered Cycle rickshaws are the common mode of transport for travel within short distances in the city. Traffic police have proposed and implemented area and time restrictions on the movement of Cycle-rickshaws in Delhi. A large number of Cycle-rickshaws in Delhi are unregistered and are illegal source of occupation for several migrants and immigrants.

The Delhi Government has signed a joint venture agreement with the Infrastructure Development Finance Company (IDFC) with 50 per cent equity participation for the Delhi Integrated Multi Modal Transit System Limited (DIMTS). The IDFC is engaged in the development of a commuter-friendly transport infrastructure in Delhi comprising the much talked about High Capacity Bus System, Monorail and Light Rail Transport systems among others.

Traffic management in Delhi

The signalised traffic control covers 701 signalised traffic intersections, of which 100 intersections are a part of SCOOT (split cycle offset optimisation technique) traffic control system. The other intersections uses signalised systems that are either based on fixed time controller or vehicle actuated traffic signalised controller (only 7 Traffic signals). Of the total, 458 intersections are fitted with traffic blinkers. A total of 15 intersections have red light and speed check cameras; and 9 intersections have installed pan-tilt and zoom camera (PTZ cameras) and 26 fixed cameras for traffic monitoring.

Proposals for measures application

Public Transport measures

- **Public Transport Network Improvement**

This measure is highly required for application in disaster-situations in Delhi. The public transport will be an effective mode of transport for disasters in Delhi due to the fact that 60-80% traffic demand is fulfilled by public transport. The public transport network improvement need to extend, re-route or modify the fixed public transport lines. The establishment and development of proposed bus-priority lanes (total proposed 103 km) is quintessential for the network improvement for disaster-situations.

- **Public Transport Scheduling Improvement**

The improvement of PT scheduling is required to ensure the maximum trips from disaster-affected or disaster-prone region to safe heavens. The scheduling improvement requires both the time and the frequency of public transport operations. The existing low frequency of Delhi Transport Corporation buses operation and other private buses operations during night hours requires scheduling improvement in order to fulfil the night-time traffic demand of public transport. The similar modifications are necessary for Delhi Metro schedules.

- **Public Transport Accessibility Improvement**

Accessibility to public transit is still a problem in many urban areas of Delhi. Most of the world standards on public transport specify the public transport within a reach of 100 metres from home. However public transport accessibility in some Delhi districts is more than 400 metres. There is a great need to connect the inaccessible areas during the disasters in Delhi by either running a separate feeder bus services or connecting it to a main public transit.

- **Public Transport Capacity Improvement**

Unlike most of the European countries, the average bus occupancy on Delhi buses exceeds 60 passengers per bus. Yet there is a great need to improve the transport capacity of most of DTC buses to reduce the number of trips per buses (total time of operations) and to satisfy the passenger demand (traffic demand) for a certain particular time.

- **Special Disaster Transport Services**

The special disaster transport services need to include the provision of operation of inter-state transport services for the capacity building of public transport infrastructure. The state transport organisations need to sign pacts or agreements to free-movement of buses within National Capital Region (NCR). Similar pacts are signed between Delhi Transport Corporation and Uttar Pradesh State Road Transport Corporation (UPSRTC).

There is also a great need to address the needs of mobility-disabled people of Delhi. These disabilities include low-income, young or old age, illness and disabilities. Considering the impacts of disaster on mobility-disabled groups, it is necessary to address their need of transport. The personalised para-transit service provides demand-responsive public transport service through the operation of low capacity vehicles such as taxis, minibuses, etc. The operation of such services would require special agreement between the service operators and the state transport authorities. Such services need to be either subsidised or free-fare to the mobility-disabled.

- **Public Transport Right-of-Way Prioritisation**

Priority lanes for the buses are the optimal solutions to the passenger demand during disasters. Delhi currently operates 5.8 km of dedicated high capacity bus lanes. The development of such lanes will solve problems of space for public transport modes especially buses. Traffic signal pre-emption and traffic signal coordination are necessary for the successful operation of HCBS buses during disasters. There is also a need to address the integrated time scheduling similar to ITF (Integraler taktfahrplan) for optimal utilisation of public transport services.

- **Public Transport Information Services**

At present the PT information is mostly static information delivered to passengers at different bus stands which provide schedules of different bus services. Recently Delhi government introduced a web portal for providing information on city bus routes. The updated information is posted on websites and provided in printed/online newspapers. The lack of information among passengers

result unfulfilled trips at a certain time, longer or shorter trips than desired trip lengths leading to increase in number of trips and longer waiting times. Lack of passenger information is crucial to the success of transport services in disasters.

Delhi Metro provides detailed static and dynamic passenger information at various metro stations. Adequate information on routes, schedules and fares are provided to passengers through maps or through personnel. Some important issues related to passenger information are: (i) unavailable and inadequate methods of information dissemination of static and dynamic passenger information to general passengers and to mobility-disabled people, (ii) poor quality of passenger information, and (iii) poor coordination among public transport operators due to lack of information.

Furthermore, the information booths for disseminating (e.g. bus-terminals) are inadequate and inefficient due to poor infrastructure. There are no dedicated mobility centres for detailed information.

- **Public Transport Management Centre**

DTC has thirty-four depots meant for parking, operation and maintenance of DTC buses. Each depot is managed by a depot manager. DTC has central control room has an accident cell as well a Central complaint cell. Most depots operate the buses according to the fixed schedules. Buses generally have no contact to the depots or any control room while operation. In cases of vehicle breakdown, the driver reports the location through a phone and a recovery vehicle is sent from the nearest depot. Unlike developed European countries, there is no dynamic control and coordination with the on-duty bus driver. The location and the other data related to DTC bus operation are not recorded through any technology.

During disasters, the availability of bus-data is necessary for the connection matching between different transport modes and for the passenger information system. PTMC during disaster is also necessary for the effective functioning of other PT measures.

- **Establishment of Pedestrian routes & Facilities**

Most urban roads in Delhi have provisions for footpaths. The study on physical characteristics of sidewalks on twelve locations in Delhi revealed poor maintenance of footpaths, inadequate footpath width, encroachments, potential for vehicle conflict and discontinuity (ITPI, 2004). Centre for science and environment (CSE), India revealed that more than 50% of the traffic accidents involve pedestrians. The walking environment also lacks the facilities (e.g. crossing facilities) necessary for the promotion of walk for short to medium distance trips. The availability or establishment of pedestrian routes in disasters will reduce the trips significantly and dependence on the motorised modes of transport. The establishment of the pedestrian routes and facilities is a dynamic TM measure which requires least cost of application and short time of activation. However there is a great need to address the issues related to pedestrian routes and facilities prior to the inclusion of this measure in the recommended measures.

- **Establishment of Bicycle routes & Facilities**

Except for few roads, bicycle routes (lanes) are not segregated in Delhi. Cyclists constitute 18% of the total traffic demand (TRIPP, 2006). Study reveals that 58 traffic zones have 5-10% bicycle traffic, 26 zones have 10% bicycle traffic and 31 zones have 3-5% bicycle traffic. In disasters, the bicycle routes can be used to reduce the total generated traffic demand (radius 3-5 km). The provision of bicycle routes for major disaster centres would involve demarcation of road space for bicyclists, adequate crossing facilities at intersections with signal control and provision of bicycle shelters at major work centres. Traffic analysis infers that it is more efficient to provide one bicycle

lane and one or two motorised lane instead of three non-segregated lanes. The vision of make Delhi a bicycle friendly city is achievable following the fact that more than 500 km of Delhi have 45m or more ROW. Bicycle master plan proposes the development of bicycle lanes on all arterial roads. The plan proposes three phased development of bicycle lanes, the first phase consists of development of 90 km routes which experience heavy bicycle traffic, the second phase includes 276km on major arterials and third phased includes 370 km on 30m ROW roads.

- **Carpooling & other Ride Sharing Programs**

Carpooling and other ride sharing programs are not widely practised in NCR including Delhi. This is primarily due to safety and security concerns associated with the shared travel. Several websites exists which promote the carpooling programs but are managed independently with less or no control and monitoring of such programs. The potential exists to significantly reduce the use of SOV and hence the total traffic demand per transport mode especially in disasters. The recommendations for the success of such program are: (i) establishment of carpooling stations, (ii) control and monitoring of carpooling practices by Delhi Traffic Police (DTP) by monitoring vehicle and driver's registration, and (iii) Travel data of carpooling customers including name, age, occupation, address, origin and destination of trip, etc.

- **Car Rental Services**

Car rental services are highly unorganised in Delhi. The taxi operators in Delhi sometimes provide car rental services without authorisation from state transport authorities. Except a few car rental companies like Hertz Car Rental, Avis Car Rental, etc., the organised car rental services are deficient. Moreover the big companies focus on higher income clientele and do not fulfil the low to medium income clientele. The car rentals are exorbitantly priced (Rs. 500-1000 within 40 km) which limit their use to higher income clientele only. Car rental companies in Delhi provide less support to car hire and promote chauffer-driven cars for more profits. There is a need to organise this sector and allow favourable competition to reduce car rentals. In additional, State Transport Corporations of Delhi (e.g. Delhi Tourism) need to provide such services. In disasters, the potential of this measure exist in reducing the public transport demand and total traffic demand by promoting high occupancy use of cars.

For the purpose of using the car rental services, the detailed information on the services providers will be required. Special agreements between the service providers and State Transport Corporations will be needed to reduce the cost of such services to the users.

- **Automobile Roadway Repair Service**

The automobile roadway repair on all roads except expressways is provided by nearby repair shops. The provision of automobile roadway repair service (including towing) is almost non-existent in Delhi. The towing of vehicle is limited to illegal parking on roads which is conducted during traffic law enforcement drives by Delhi Traffic Police.

There is a need to establish service points at several locations on Delhi highways and other roads within urban areas. They need to provide preventive to full maintenance solutions for multiple transport modes. The service need to consist of repair, towing and quick service facilities at regular intervals on roads. This service could be coordinated with the existing fuel and rest stations on Delhi highways and roads within urban areas.

- **Special Traffic Rules Enforcement**

Traffic rules enforcement in Delhi and largely in India is a unique challenge. In general, traffic rules are often violated by road users and the rules are not properly implemented by the enforcing

agencies. In disasters, enforcement of new traffic rules and regulations is required. Such rules would require adequate institutional participation and public acceptance. The traffic rules implemented during disasters need to address the following issues more precisely: (i) vehicle improvement rules, (ii) speed limits and overtaking restrictions, (iii) parking restrictions, and (iv) high occupancy vehicles and disaster traffic priority system.

- **Economic or Preferential Incentives**

The IMT modes (cars and two-wheelers) in some cities of India including Delhi account to 90% of total vehicles. Contrary to the above fact, the modal split indicates that public transport still fulfils 60-80% of the traffic demand in Delhi. This phenomenon pose challenges to the policy planners with regards to the provision of economic or preferential incentives to the road users including passengers (public transport users). The policy planners are indecisive to promote and patronise the use of transport modes by providing economic and preferential incentives. Based on the census data and motor vehicle statistics, car occupancy rates are 184 cars per 1000 population and 78 motorcycles per thousand populations.

Considering the modal split of Delhi, it is clear that public transport is the favourable mode of transport among most people. Therefore economic and preferential incentives should be provided to the public transport to encourage its use.

- **Trip reduction & Land-use Modification Ordinances**

During disasters in Delhi, all traffic-generating institutions and offices need to close temporary to reduce the traffic demand. Delhi is a polycentric city which requires even implementation of trip reduction and land-use modification ordinances in order to reduce the total traffic demand. The other methods to reduce the traffic demand are: (i) promote tele-working, (ii) promote alternate time-schedules, (iii) Implement certificate scheme to limit the dispensable disaster tourists, research groups or media, (iv) promote inter-operability of transport modes, and (v) promote trip chaining programs.

- **Road Network Control**

Delhi Traffic Police is the first traffic management agency for the Delhi city. The traffic management measures implemented by DTP are traditional and involve low to none use of advance technologies such as dynamic message signs, traffic monitoring stations, traffic collection points, traffic information and traffic management centre. The use of manual traffic control does not provide solutions of traffic control in Delhi. Therefore the use of advance traffic control and traffic information systems is inevitable for cities like Delhi. The applications of road network control for disaster in Delhi are: (i) diversion routes for evacuation and disaster management support, (ii) Use of secondary roads, (iii) Alternate routes, (iv) Contra flow roads and (v) Lane management. The road network control pre-requisites the implementation of access and parking restrictions.

- **Road Section Control**

Road section control is a measure to ensure the safe driving conditions to the traffic. The applications of road section control are: (i) lane management and control through turning movement and overtaking restrictions, (ii) speed zoning and management and (iii) use of traffic control devices e.g. signs, signals and markings. The implementation of dynamic message signs is useful to disseminate the changeable and updated information based on current traffic characteristics and local environmental conditions during disasters. The use of static message signs limits the application of dynamic traffic control and information.

- I**mprovement of Signalised Traffic Control**

Two important applications of this measure are traffic signal pre-emption and traffic signal control. In disaster cases where disaster traffic is sharing the same road, the priority is needed for the disaster vehicles requiring immediate access to the disaster site. Similarly the priority is required for improving traffic flow conditions and minimising the response and recovery times of disaster vehicles. In order to implement priority and the coordination of traffic, integration of all the upstream and downstream intersections is required on the desired corridors. Also additional infrastructure for detection of disaster vehicles by installing beacons and detectors is required. Signal controllers compute the signal timings to ensure the green-wave to the different streams of traffic.

- **Improvement of Non-signalised Traffic Control**

The use of static and dynamic traffic signs, road markings and miscellaneous traffic control devices is required to improve the traffic flow conditions. The improvement of non-signalised traffic control is also needed to improve the space allocation to traffic by modifying road geometrics. The use of non-signalised traffic control would required the extensive procurement of barricades, traffic cones, ropes, central refuges, speed breakers, lighted traffic bollards, reflective devices, etc. by the traffic management agencies such as DDA, NDMC, DTP etc. An application plan of non-signalised traffic control is required to conform to the signalised traffic control.

- **Improvement of Inter-modal and Parking Facilities**

Parking is deficient in Delhi due to mismanagement as well as due to shortage of the parking spaces. The non availability of parking is counter-effective to multiple TM measures and this issue need to be adequately addressed in traffic management.

In cases of shortage of parking places, land use modification ordinances will be required. Such ordinances will make effective use of available non-designated places such schools, depots, terminals etc. for parking purposes. Formal agreements between space providers and traffic management agencies will be required to ensure the availability of parking places during disasters.

- **Traffic & Disaster Information Service**

In order to operate the information service, traffic information booths run by Delhi Traffic Police will be required. The dissemination of dynamic information to the road users and non-road users is currently difficult due to unavailable infrastructure and technologies. However traffic control cell of Delhi Traffic Police can provide the relevant data dynamic to various radio and TV channels for quick dissemination of information to the road users. The information provided by radio and TV channels should include the location of event (incidents/congestion/disaster), time of event, consequence of event and traffic-related detours.

- **Disaster Traffic Management Centre**

Depending on the scale and type of disaster, the establishment of DTMC will be necessary. In case of long-duration disasters, DTMC could be established at or near the disaster site. The primary functions of the centre are: (i) to coordinate with the other sub-centres or information booths, (ii) to coordinate with work zones, (iii) to collect and disseminate traffic and disaster information, (iv) to provide traffic management in the disaster-affected area.

- **Work- Zone Coordination & Management Centre**

The establishment of bicycle and walking routes in the work zones are necessary. The centre will provide management of time, construction and activities to use the synergies of other construction units by controlling the time of operation of work zones.

- **City Logistics System**

This measure is complemented by freight traffic operations control. Such controls will promote the use of small size vehicles for delivery and optimising the use of capacities of other freight transport vehicles. Empty haulage will be utilised. Other benefits are that the collection and distribution points will be minimised and less traffic is generated. Establishment of freight complexes will provide bulk breaking points and parking possibilities.

- **Household Goods Delivery Transport System**

The establishment of this system will collect information on the required household goods by the people in the disaster-affected area and distribute the goods by operating smaller vehicles for delivery. Public distribution system of Delhi should operate such services during disasters.

- **Freight Traffic Operations Control**

Freight traffic operations control is the application of the time and destination restriction on different freight transport modes. Application of such a type of control during disaster response may be counterproductive for the process of disaster management. However such control needs to address the use of road space for all potential road users. The control will be coordinated with the application of city logistics in the provision of parking spaces for trucks, lorries and trailers. All the traffic control points need to be located at the entry and five exit points of Delhi.

Requirements of application of TM strategies in Delhi

The strategies are formulated by combining the basic measures and the complimentary measures. The complimentary measures are either supportive measures or difficulties-solving measures. Such supportive or difficulties-solving measures are intended to either improve the effectiveness or reduce the difficulties in the implementation of a measure. The supportive measures use the synergies of other measures. The difficulties-solving measures are applied to reduce the difficulties of implementation of the basic measures. However compatibility checks are required between the basic measures and the complimentary measures for their supportive and difficulties-solving nature. The compatibility of the basic measures with the supportive or conflict-solving measures is required.

- **Strategy to avoid or reduce unnecessary car-based mobility**

The current political and administrative framework is utilised for the application of this strategy. The National Disaster Response plan prepared by High Powered Committee (HPC) utilised the empowered group of ministers for the purpose of initiating the necessary political and administrative actions. The reduction of car-based mobility will however depend on the scale and type of disaster impacts. Strict implementation of land-use zoning regulations will be required in order to reduce the trip lengths, trip origins and trip destinations. The land-use zoning plans are necessitated for the development in disaster mitigation and preparedness phase. The improvements are required in public transport (mainly DTC buses) in terms of network, scheduling, accessibility, capacity; parking and priority of DTC (bus lanes and bus priority at intersections). Road pricing can be implemented in disaster recovery to reduce the use of car by providing economic disincentives e.g. higher parking fares, restricted parking for cars, access restrictions, etc. The respective institutions for this implementation are NDMC, PWD, MCD, DDA and Delhi Cantonment Board. Traffic control in urban areas (Urban traffic control) which involves especially access restrictions for cars is required in the disaster response phase.

Possible modules of the strategy: Political and Administrative Framework, Land-Use Zoning Regulations, Public Transport Improvement, Road Pricing, Urban Traffic Control, Traffic and Disaster Information Management, Traffic Education and Public Awareness, etc.

- **Strategy to increase the vehicle utilisation of transport modes**

Vehicle utilisation of transport modes would include capacity enhancement or capacity utilisation of all transport modes in Delhi. The users of IMT modes such as cars, taxis and autorickshaws need to promote carpooling and carsharing practices. In public transport, capacity enhancement by operating high capacity buses on high-demand PT routes need to be considered. Similarly public transport scheduling improvements are required to improve the PT ridership and integration with other modes. In freight transport, city logistics system is required for coordinating operators with similar origins and destinations. Furthermore, the traffic and disaster information management would ensure the dissemination of information to the road users. The application of this strategy will involve extensive traffic education, training and public awareness programs.

Possible modules of the strategy: Political and Administrative Framework, Capacity Utilisation of Transport Modes, Traffic and Disaster Information Management, Traffic Education and Public Awareness, etc.

- **Strategy to shift the use of individual motorised transport**

Public transport is a feasible option to evacuate or re-entry pertaining to the disaster-affected or disaster-prone areas. However complete reduction of IMT modes is not desired, this measure pertains to shift the use of IMT to other modes such as PT and NMT. This strategy would economic and preferential incentives and disincentives for using IMT. The approval of political organisations in limiting the use of IMT is required due to need of public acceptance and institutional participation. The modification of land-use patterns will prohibit the use of some areas to IMT modes. On parallel terms, the improvement of non-motorised infrastructure and operation is needed. Similarly, the PT improvements are required especially in enhancing accessibility, scheduling, capacities and parking facilities for the success of this strategy. Adequate information dissemination methods and public awareness are necessary to promote the use PT and NMT modes.

Possible modules of the strategy: Political and Administrative Framework, Land-Use Zoning Regulations, Non-Motorised Transport Improvement, Public Transport Improvement, Traffic and Disaster Information Management, Traffic Education and Public Awareness, etc.

- **Strategy to improve the spatial distribution of traffic volume**

This strategy is suitable to reduce congestion on roads in disaster-affected or disaster-prone areas. The temporary closing of establishments is necessary to shift traffic on alternate routes and destination. This involves land use modification to support its implementation. More direct application of this strategy is the inter-urban and urban traffic control which involves measures which restricts the access of IMT modes and diverts the IMT traffic.

Possible modules of the strategy: Political and Administrative Framework, Land-Use Zoning Regulations, Inter-Urban and Urban Traffic Control, Traffic and Disaster Information Management, Traffic Education and Public Awareness, etc.

- **Strategy to improve the temporal distribution of traffic volume**

The temporal distribution of traffic volume includes providing economic and preferential incentives for different times for different transport modes. The temporary changes of land-use can be used to

shift traffic temporally. The allotment of slots to freight traffic also distributes traffic temporally. The provision of transport and disaster related information (static and dynamic) will be required. Furthermore, alternate and flexible work schedules promoted by different organisation will require adequate traffic education and public awareness.

Possible modules of the strategy: Political and Administrative Framework, Land-Use Zoning Regulations, Freight Transport Improvement, Traffic and Disaster Information Management, Traffic Education and Public Awareness, etc.

- **Strategy to improve the transport supply capacity**

Under this strategy, the transport supply capacity is improved. In public transport, the high capacity modes and additional coaches will be introduced to accommodate high traffic demand. The improvement in parking facilities of buses will require the provision of land-use zoning regulations to use the available spaces such as schools, playground, stadium, etc. In NMT category, this strategy will provide road markings and the shelters for pedestrians and cyclist. In IMT category, inter-urban and urban traffic control is required especially by establishing diversion routes, lane management and control, speed zoning, traffic signal prioritisation, traffic signal coordination and the improvement of parking and intermodal facilities.

Possible modules of the strategy: Political and Administrative Framework, Land-Use Zoning Regulations, Public Transport Improvement, Non-Motorised Transport Improvement, Freight Transport Improvement, Traffic and Disaster Information Management, Traffic Education and Public Awareness, etc.

- **Strategy to reduce traffic accidents and their impacts**

This strategy will be implemented to reduce the traffic accident both in number and fatality on Delhi roads. Anticipating the increase of traffic accidents due to bad-weather conditions following a natural disaster, this strategy involves the strict implementation of special rules and regulations developed for disasters. Inter-urban and urban traffic control is required for speed zoning, access restriction, etc. Traffic incident management is also required to reduce the trip-times involving traffic accidents and incidents. Adequate and timely dissemination of traffic and disaster-related information is necessary for the success of this strategy. Furthermore the traffic education and public awareness programs are required for this strategy.

Possible modules of the strategy: Political and Administrative Framework, Inter-Urban and Urban Traffic Control, Traffic Incident Management , Traffic and Disaster Information Management, Traffic Education and Public Awareness, etc.

- **Strategy to improve integration between traffic-related activities**

This strategy is required in disasters to utilise the potential of integrating transport modes. The application of Integraler Taktfahrplan (ITF) for public transport scheduling is effective to use the synergies of integration of several transport modes. The change of the designated use of transport modes for reducing the empty haulage of modes is required to increase the transport supply. The work-zone management is required for coordinating different work-zones to maximise the resource utilisation in disasters. The integration between traffic-related activities in the work-zone is based on resources such as manpower, time of operation, cost of operation and transport infrastructure. Aggregation and distribution patterns of freight need to changes as per city logistics system.

Possible modules of the strategy: Political and Administrative Framework, Public Transport Improvement, Freight Transport Improvement, Work Zone Management, Traffic Incident Management, Traffic and Disaster Information Management, Traffic Education and Public Awareness, etc.

- **Strategy to reduce the disturbances of traffic flow**

The traffic flow disturbances other than due to work zones and traffic incidents are a part of inter-urban and urban traffic control which deals with lane management, speed zoning, improvement of signalised and non-signalised traffic control, etc. Political and administration implements a set of special traffic rules to reduce the traffic flow disturbances.

Possible modules of the strategy: Political and Administrative Framework, Inter-Urban and Urban Traffic Control, Work Zone Management, Traffic Incident Management, Traffic and Disaster Information Management, Traffic Education and Public Awareness, etc.