Environment-responsive Traffic Control

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Abstract

This article describes some fundamentals for an environment-responsive traffic control. It starts with a brief description of the needs to consider environmental aspects in urban traffic control, focusing on noise, particular matters (PM), and nitrogen oxides (NOx). Respective current regulations by law in Europe and Germany are explained. Comparing the regulations for the improvement of air quality and for noise reduction, important similarities and differences are pointed out.

In the next section, the idea of a dynamic traffic control is introduced, which takes into account not only the traffic situation, but also the current environmental situation.
Systematically, the different options of dynamic measures to influence traffic volumes and traffic flow are being analyzed and assessed for their general potential to improve the environmental situation while avoiding unnecessary restrictions for motorized traffic.

An overview on measures is given which have been applied so far to improve the environmental situation, concentrating on traffic control measures. E.g. this includes approaches to optimize traffic signal control, restrictions for heavy vehicles to pass certain parts of the network, “environmental zones” (Umweltzonen), and speed limits.

Furthermore, different methods to assess the potential of traffic control measures as a basis for a situation-dependent selection of measures are described, especially regarding the quality of their results (accuracy, time resolution, and spatial transferability).

Concluding, research and development needs are outlined.

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1. Introduction

Until 2005, the public awareness of environmentally oriented traffic control (as well as other related traffic management topics) has been insignificant. Yet after legal thresholds for particulate matter were obliged in recent years, people experienced environment-related traffic restrictions and realized more and more one imminent goal conflict in traffic engineering: Accessibility versus environmental impacts.

In the year 2006, the European directive for the assessment and management of environmental noise [5] was transferred into German national law and brought new requirements into focus. Thereby, another (of course already known but often neglected) goal conflict had to be considered: Improving air quality (which usually means distribution of traffic streams) versus noise reduction (which often means bundling of traffic streams). Further goal conflicts come up with the secondary effects of many measures, e.g. by shifting traffic and environmental problems to suburban areas or other parts of the road network.

All these goal conflicts gain even more weight, since the implemented measures often implicate harsh restrictions for urban traffic, and therefore, have negative impacts on the efficiency of transport and the corresponding economical processes. Since the measures mostly are of static nature, they are effective also in times when the situation (e.g. weather conditions, traffic volumes) does not require them.

The mentioned developments are indicating clearly, that traffic control should support the needs of mobility as well as the needs of environmental protection by selecting the control measures under consideration of the actual situation of traffic and environment. Of course, there are certain conditions that have to be considered before an effective environment-responsive traffic control can be implemented. But first implementations, such as in the town of Hagen [1], show that in many cases dynamic measures could be very advantageous to deal with the mentioned goal conflicts as well as to avoid unnecessary restrictions for the users of the urban road network.

In the following, the environment-responsive traffic control will be presented under consideration of the *legal context.* Relevant *control parameters* and possible traffic control *measures* will be pointed out and an approach for the *evaluation* of the measures will be explained. Concluding, recommendations for further development and research needs will be given.

2. Legal Context

Dynamic traffic control measures focus on the improvement of situations, which occur only within limited periods. As a motivation for the responsible municipalities to implement such measures, there has to be a significant benefit regarding the legal requirements. Therefore, the current (and future) legal situation in air quality monitoring and noise reduction is briefly described, and the relevant aspects for situation-based traffic control measures are highlighted.

Air Quality

The European Council directive 96/62/EG [3] and the corresponding directives [4] brought in a first stage of legal thresholds for PM_{10} and for NO_2. These thresholds which are defined on hourly (NO_2), daily (PM_{10}), and on yearly basis (NO_2 and PM_{10}), must not be exceeded in “agglomerations” (“Ballungsräume”) and in “zones” (“Gebiete”). The mentioned directives also scheduled a second stage of thresholds for the year 2010. Then the thresholds for PM_{10}

should be lowered. Furthermore, the directives described the monitoring methods regarding quantitative and qualitative aspects of data collection.

In 2008, the new directive 2008/50/EG [6] was passed into European law. It integrated the existing directives and showed an updated content. This update reflects the experiences with the former directives as well as the state of research. Most important changes are

- the consolidation of the former directive 96/62/EG and of the corresponding directives 1999/30/EG, 2000/69/EG, 2002/3/EG and 97/101/EG to one directive,
- the introduction of a long-term threshold for the $PM_{2,5}$ exposition (as a target value until 2015, from then as a liable threshold),
- weakened deadlines for complying with the thresholds if certain conditions are fulfilled,
- and the introduction of a new planning instrument “short-term action plans” (“Pläne für kurzfristige Maßnahmen”) to minimize the risk of exceeding the “alert thresholds” (“Alarmschwellen”) where an exceeding within a short period (3 hours) can bring forth negative health impacts.

Although some of the changes, such as the consolidation of the different directives and the implementation of a $PM_{2.5}$ threshold, are being approved, the authors are skeptical about the impact of the canceled second stage for PM_{10} and the weakened deadlines for complying with the thresholds:

- It reduces the planning reliability for emitters and regulatory authorities and, thereby, also the acceptance of the directive within these groups.
- It creates the impression that there is still uncertainty regarding the impact and the evaluation of the PM_{10} exposition[1].
- With regard to the court decision of the European Council from 25th July 2008 [7], the changes lead to an inconsistency: On the one hand, people may prosecute a claim for the development of an air quality plan. On the other hand, there is no obligation for efficiency or in general for the quality of this planning (q.v. [14]), because the liability of the regulations has been weakened.

Noise Reduction

In 2006, the European directive for the assessment and management of environmental noise [5] was brought into German national law. Its content was transferred into the national regulations “Bundesimmissionsschutzgesetz” [2] and the “34. Bundesimmissionsschutzverordnung” [15]. Therefore, the responsible municipalities were obliged to create noise maps and prepare action plans to reduce noise exposure.

Different to air quality, noise should be reduced when it is being sensed as a disturbance and not only when explicit negative health effects can be expected.

On the first impression, this definition seems to fit into the concept of a dynamic, situation based strategy, by which the exposition during short peak periods at certain places will be

[1] As there is no corresponding English expression for the German word “Immission”, the word “exposition” is used for the concentration of pollution to which individuals are exposed.

reduced. However, the main (non-static) input parameters for the evaluation of noise are based on average yearly values.

Furthermore, traffic law measures are only permissible if their reduction potential is at least 3 dB(A) [10], which is comparable to reducing the traffic volume approximately by halve.

Conclusions for the Conception of an Environment-responsive Traffic Control

- The new directive for air quality does not implicate relevant changes for the conception of dynamic traffic measures. The currently relevant short period thresholds for PM_{10} and NO_2 remain unchanged.

- An important precondition for the positive impact of a dynamic traffic control is that the agglomeration shows exceedings of short-period air quality thresholds.

- Regarding the noise reduction, the current legal situation uses average long-term values as input parameters for the evaluation of noise. However, because the noise load is often very heterogeneous in its magnitude and because the sensitivity of the environment also underlies variations, dynamic measures during critical periods could still contribute to complying with long-term-thresholds.

- The implementation of restrictive traffic measures to reduce noise is quite difficult, because the noise reduction potential has to reach at least 3 dB(A). Hence, the argumentation with air quality improvement may be easier for the responsible authorities although noise reduction is targeted, as well.

3. Relevant Boundary Conditions and Parameters

In this contribution, we distinguish between some fundamental boundary conditions, which have to be considered to achieve a positive impact of the traffic control measures, and relevant parameters, which are of dynamic nature and have to be processed in the traffic control. The parameters themselves can be classified into parameters for the macroscopic control level and parameters for the microscopic control level. According to [8], the macroscopic control level takes into account long-term changes (e.g. daily changes), while the microscopic control level takes into account short-term changes of certain parameters (e.g. changes within minutes or seconds).

The **boundary conditions** that have to be considered for a proper function include at least the following points:

- The *critical places* where air quality and noise often exceed the legal thresholds have to be identified[2] and implemented in the control algorithms.

- An important requirement for the planning reliability and, therefore, for the acceptance of such measures as well as for the in-time activation is the *predictability* of the exposition to air pollution and noise. E.g. regarding air pollution, a high forecast quality for weather conditions and for the regional exposition is very important. Regarding noise, the forecast quality of the traffic volume and especially the traffic volume of heavy vehicles is important.

[2] Usually the critical places already have been identified by the local authorities, so the traffic engineer only has to implement the existing data.

- The *response time of the cause-and-effect-chain* has to be taken into account. While the reduction of the traffic volume almost instantly results in reduced noise exposition, it surely takes more time until the traffic-related particle exposition decreases, depending on ventilation and other influencing factors.

Furthermore, the following **parameters** have to be considered:

- Of course, an environment-responsive traffic control system has to take into account the traffic conditions. Relevant traffic parameters are *traffic volume, traffic volume of heavy vehicles, average travel time, average number of stops, time headway, etc*. Some of the parameters, such as the traffic volume and its variation in time patterns are used for both the macroscopic and the microscopic control level. Some others, such as time headway are only suitable for the microscopic control level.

- *Main routes* in the network and *alternative routes,* which can be used to shift traffic from critical places to less critical places, have to be defined. Because of its time-dependence, this parameter should be implemented on the macroscopic control level.

  The *actual environmental situation and its forecast* have to be taken into account. This includes the measured PM_{10}, NO_2, and meteorological conditions at the traffic hot spots and the background stations. Additionally, measured or modeled values at other hot spots or near alternative routes may be used. Because of the tight connection between PM_{10}, NO_2-emissions, and traffic flow, the near-traffic values seem suitable for the microscopic control level, while the background data seems suitable for the macroscopic control level. The noise exposition at the defined critical places has to be modeled. Because of its often day-type-dependent magnitude, it seems suitable for a consideration on the macroscopic control level, as well.

- Another exposition-related parameter is the *temporal and spatial variation of the exposition*. Regarding air quality, this means the difference between the hot-spot exposition and the urban background exposition and their proportion. Depending on the share of urban background exposition, more wide-area measures or more local hot spot measures should be activated. Regarding noise, the average daily exposition strongly depends on the (heavy vehicle) traffic volume. As the traffic volume of heavy vehicles is usually high during working days and very low during weekend and holidays, this has to be considered on the macroscopic control level.

- As the *noise- and air pollution-affected population* shows a temporal and spatial dynamic, this must be taken into account as a control parameter. The dynamic depends mainly on the type of land-use. E.g. in a retail area, probably there will be a high level of affected population during shopping hours while that level will be quite low during the night time. A consideration for the macroscopic control level seems suitable.

4. Suitable Traffic Control Measures

The basic aim of environment-responsive, dynamic traffic control measures is to minimize restrictions to those times, situations, and locations when and where they are really needed.

The situations, *when* measures have to be activated, depend strongly on the boundary conditions, the macroscopic and microscopic parameters as explained above, and, of course, on the quantified effectiveness of certain measures in specific situations, which will be addressed in more detail in the following chapter.

The locations, *where* measures have to be applied, do not depend exclusively on where the problem occurs, but primarily on the type of measure that is suitable to solve the problem. Measures can be applied on the following spatial levels:

- *The border of the network* (e.g. by metering accessing traffic streams)
- *The network itself or parts of it (e*.g. by shifting traffic volumes)
- *Certain related or crossing arterials* (e.g. by prioritizing certain arterials)
- *Single arterials* (e.g. by prioritizing directional streams).
- *Single intersections* (e.g. by prioritizing certain streams)

Generally, the following categories of measures can be used to improve air quality and to reduce noise in the context of a dynamic traffic control:

- *Traffic signal control:*
  This category includes measures to coordinate and optimize traffic signal control for different spatial levels as mentioned above. Basically, the emissions of air pollutants can be reduced by minimizing the number of stops.
  However, the quality of traffic flow is not an input parameter for the evaluation of noise in the legal context. Nevertheless, traffic signal control can be used to reduce the (legal) noise level by metering the accessing traffic streams, as the traffic demand is an important parameter in the modeling of noise exposition.
  If traffic signal control is used to meter the accessing traffic, it should be used in combination with the measure-category “dynamic routing”.

- *Access Restrictions:*
  This category includes measures, which focus on certain parts of the network and certain types of traffic, such as through-traffic, or on certain traffic participants, such as vehicles with a specified emission-standard. It also includes mobility pricing measures, such as congestion charges or object pricing. All measures in this category are suitable to improve the exposition of both air pollutants and noise. Of course, their impact finally depends on the restricted road users and their cause’s portion to the emission.
  Measures of this category should be used in combination with “dynamic routing”, as well.

- *Speed limits:*
  The reduction of the allowed driving speed is an important measure to reduce noise. E.g. the change of the speed limit from 50 km/h to 30 km/h reduces the noise level by approximately 2 to 3 dB(A).
  As far as the reduced driving speed improves the traffic flow, the measure is also suitable to reduce the emission of air pollutants. A general statement that the reduction of driving speed is improving the air quality is not possible since the emission of different vehicles strongly depends on the engine type and on the driving behavior.

- *Dynamic routing*:
  With this category of measures, traffic demand can be shifted from (environmentally) critical parts of the network to less critical parts. Since the traffic volume is reduced in the critical area, this measure is suitable to improve the exposition to air pollutants and to noise, as well.

The following figure combines the explained parameters and the potential measures in form of a closed-loop system.

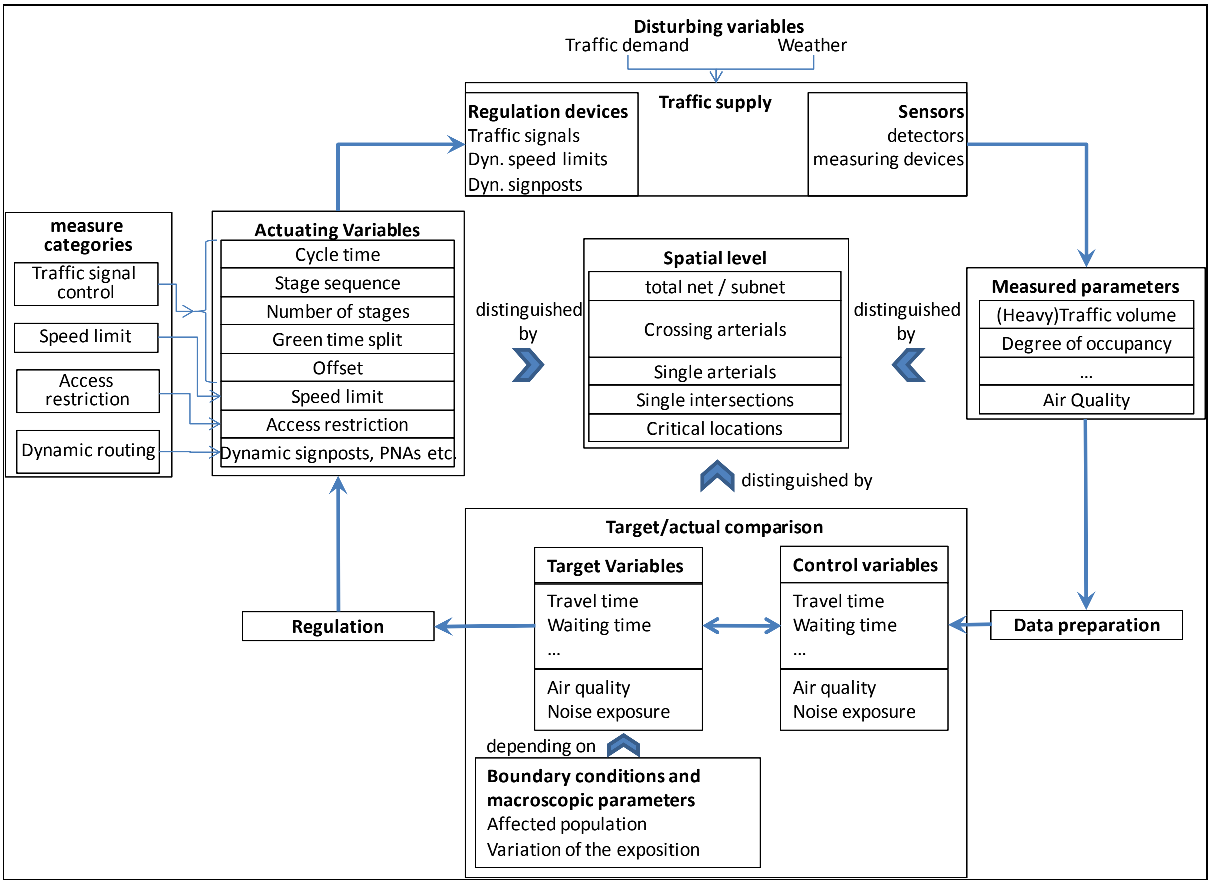

Figure 1: Possible parameters and potential traffic control measures [own illustration]

5. Evaluation Approaches

Air Quality

Generally, measures can be evaluated by physical measurement or by modeling, either of the emissions or of the exposition (immissions).

The measuring or modeling of the exposition seems to be more adequate to assess the potential of certain measures to improve air quality, since the modeling of emissions misses some important influencing factors as shown in Figure 2.

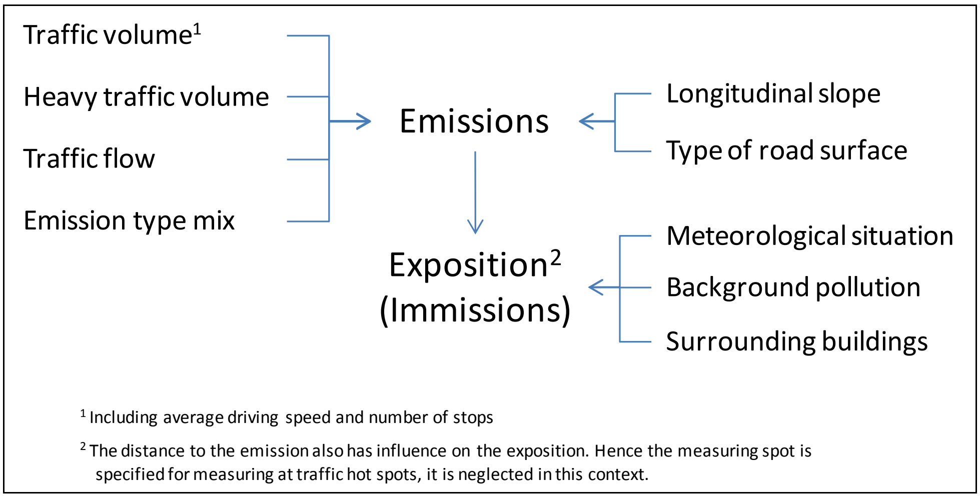

Figure 2: Factors influencing the emissions and the exposition (immissions) [own illustration]

Indeed, collecting or modeling the mentioned type of data seems to be quite difficult. This is also shown by the following fact: The European directive 2008/50/EG claims a level of uncertainty of not more than 25% for PM_{10}, respectively 15% for NO_2 measurements, and an uncertainty of not more than 50 to 60% for modeling NO_2 values. Regarding the modeling uncertainty for PM_{10}, there is not even an indication given. The validation of existing models shows that these requirements fit with the current state of research and model development. According to [13], the uncertainty in modeling is often caused by the inexact input data.

Furthermore, the minimum disaggregation level for fixed measurements is usually on an hourly basis, even often on a daily basis.

This fulfills the current legal requirements, but for the assessment of traffic control measures, neither the disaggregation level nor the accuracy seem to be sufficient since the reduction potential of these measures will mostly be in the lower percentage range.

Several research projects such as “iq mobility” [9], “Untersuchung der Einflussmöglichkeiten verkehrsadaptiver Netzsteuerungen auf die Emissions- und Immissionsbelastung städtischer Straßennetze“ [12] or “AMONES” [11] are currently trying to gain deeper knowledge on the impacts of traffic control measures on air pollution. In the following, the methodical approach of the research project AMONES is explained roughly.

The used approach tries to improve one of the main weaknesses of many evaluations and also of the modeling performance - the rough input data - by collecting extensive data on a microscopic level: Traffic flow (e.g. starting cars and passing through cars, vehicle type etc.), meteorological and air quality conditions are collected at traffic hot spots in high time resolutions (< 1 minute).

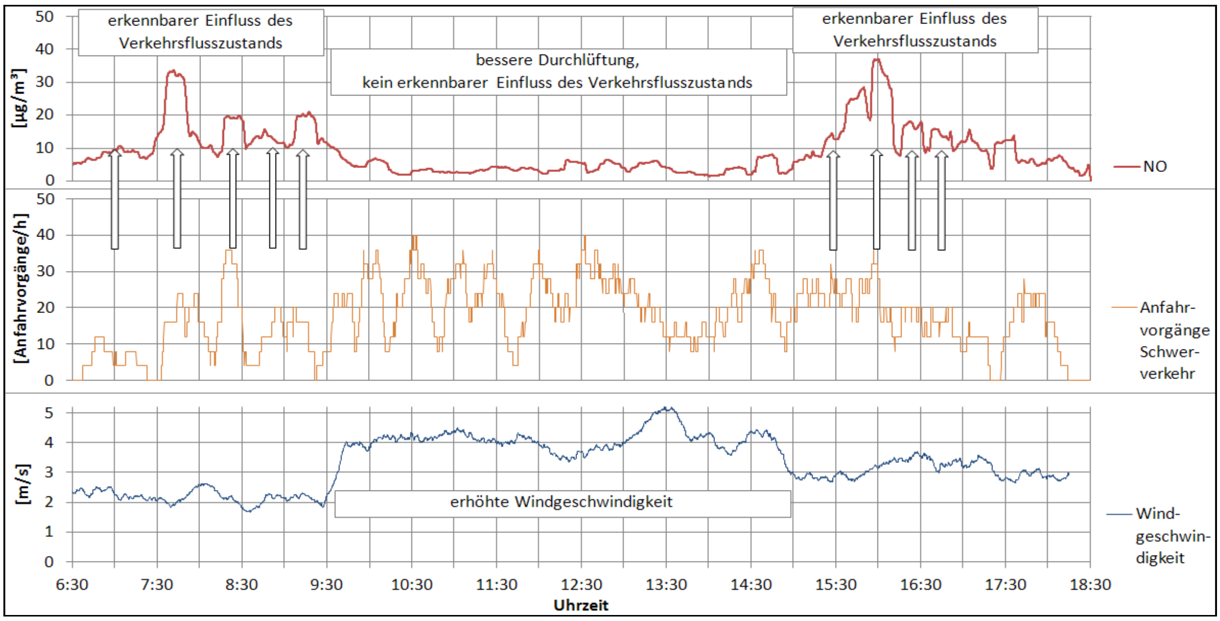

Figure 3: Example of some collected traffic, meteorological and air quality data at one section [own illustration].

The collected parameters are analyzed to quantify the cause-effect-relationship between traffic flow and the measured air pollution exposition. The results of this microscopic level analysis will be compared with standard parameters for traffic flow quality and can then possibly be extrapolated to larger spatial patterns, using standard detector data or microsimulations.

Noise Reduction

Traffic related noise is exclusively modelled, because physical measurements include too many random influences and cannot deliver adequate transparency, so far. Main input parameters are the distance to the place of exposition, the road surface type, the traffic demand, the share of heavy vehicles, and the driving speed.

Although some relevant input parameters (such as current weather conditions or the quality of traffic flow) are neglected, the impact of most of the above-mentioned measures can be roughly evaluated.

6. Research and Developement Needs

This contribution clearly shows that quite much basic research and development is needed to allow an appropriate environment-responsive, dynamic traffic control. This includes the following aspects:

- Consolidation and integration of the legal frame for air quality monitoring and for noise reduction, especially with regard to the liability, to the specification of thresholds and to the required processes for action planning.
- Elaboration of fundamental recommendations on the handling of goal conflicts.
- Further fundamental research in the cause-effect-relationship between the various influencing factors and the exposition. The potentials of traffic-related measures to improve the exposition and the sensitivity of the impacts to the influencing factors have to be quantified.

- Specification of the relevant measurands and the required measuring quality. Closely related to this topic, there is a need for a more intensive teamwork between experts in traffic engineering, in environmental aspects, and in software engineering, so the quality of the input parameters for the various modeling tools can be improved.

- Which measures strengthen each other, which measures suppress each other, or show overlapping effects.

- Consequent validation of the adequacy of measures, as recommended in the European directive 2008/50/EG [6]. This should include an assessment of the negative impacts on accessibility and economical processes.

- Development of algorithms for dynamic, environment-responsive traffic control.

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