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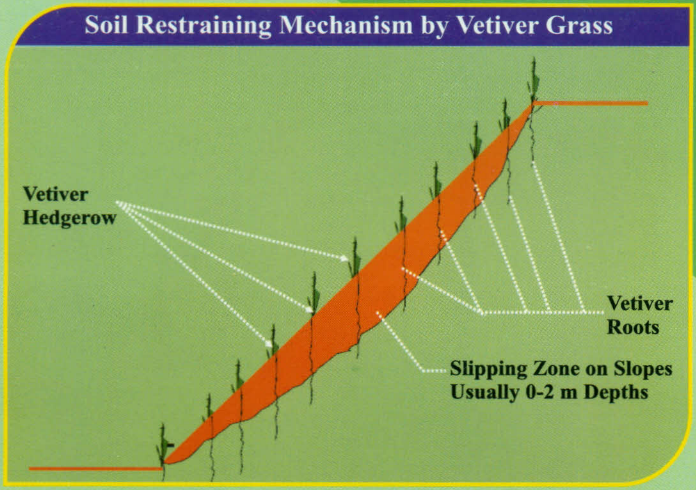

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ROLE OF FARE MODEL IN DESIGN OF RURAL FEEDER SERVICE WITH FIXED-ROUTE FIXED-SCHEDULE FORM OF OPERATION†




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ABSTRACT

All major or higher order roads in rural India are generally served by the bus system. But, the access to bus stops from villages using an appropriate feeder service is largely a missing component. With the development of rural roads through Pradhan Mantri Gram Sadak Yojana (PMGSY), it has now become possible to operate feeder service between villages and bus stops. Accordingly, the design of rural feeder service has become a necessary task in Indian context. Fare or the direct cost of travel is one of the most important parameters in the context of rural feeder service. In the present work, an investigation is made on the role of fare model in design of rural feeder service with fixed-route fixed-schedule form of operation. A simulation based approach is applied for design of rural feeder service with three different fare models. The work is demonstrated with reference to a case study in rural India. The benefit to rural population from feeder service is measured using a comprehensive measure of disutility called as Generalized Cost (GC). The work justifies the need for developing an appropriate feeder service in rural India. The effects of fare model on GC savings, percentage of road length served directly by feeder service, etc. are analyzed to understand the role of fare model in design of rural feeder service.

1 INTRODUCTION

Bus system plays a vital role in rural India. Presently, majority of higher order roads such as National Highways, State Highways and Major District Roads are served by the bus system. However, due to poor condition of roads and lack of availability of feeder service, rural commuters have predominantly used walking and bicycle to access bus stops. In the recent years, the road connectivity in rural India has improved significantly with the construction of rural roads under Pradhan Mantri Gram Sadak Yojana (Sikdar 2002), and accordingly it has become possible to operate feeder service between villages and bus stops. Although several studies have been reported in literature on routing, scheduling and design of feeder service in urban areas (Wirasinghe 1980; Geok and Perl 1988; Martins and Pato 1998; Shrivastava and Dhingra 2001; Shrivastava and O'Mahony 2006, 2009; Li and Quadrifoglio 2010), there is little information available regarding the design of rural feeder service in developing countries. Das et al. (2012) demonstrated an approach for the planning of feeder service in rural India with fixed-route fixed-schedule form of operation. The work demonstrated an approach for the selection of feeder route, vehicle, service headway, fare etc. with due consideration to the operational viability of the service. However, the time headway for arrival of passengers at a feeder stop during an hour was assumed as constant which resulted into

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equal loading of all vehicles, and average delay per passenger as half the headway of service during that hour. In reality, the arrival of passenger follows a random distribution and all vehicles during an hour are unlikely to be loaded uniformly. Also, the average delay per passenger may be higher or lower than half the headway of service depending on the arrival of passenger at feeder stops. The methodology suggested by Das et al. (2012) is modified and a simulation based approach is followed in the present work for the design of rural feeder service. In the simulation model, the arrival of passenger at feeder stops is assumed to follow a uniform random distribution. Fare or the direct cost of travel is one of the most important parameters in the context of rural feeder service. In the present work, three fare models are investigated in order to understand the role of fare model in the design of rural feeder service.

Das et al. (2009) reported WTP of rural trip makers with respect to various attributes of feeder service for which about 200 square-km area in the state of West Bengal, India was selected as the case study. Das et al. (2012) demonstrated an approach for planning of rural feeder service with reference to the same study area. As the present work is an extension of work reported by Das et al. (2009) and Das et al. (2012), the design of feeder service using a simulation based approach is also demonstrated using the same study area. The study area is bounded by National Highway (NH) in the Eastern side, Major District Roads (MDRs) in Northern and Western sides, and river Subarnarekha in the Southern side. The NH and MDRs are served by bus. However, the roads within the study area are not yet served by any feeder system. The study area is presently served by twelve bus stops which are located on the study area boundary.

2 METHODOLOGY

The methodology for the present work is developed by making suitable modifications in the methodology suggested by Das et al. (2012) for the planning of rural feeder service with fixed-route fixed-schedule form of operation. A major change is the generation of arrival time of passengers at stops following a uniform random distribution and calculation of user costs based on simulation runs. Das et al. (2012) considered two groups of user namely 'bicycle users' and 'motorcycle users'. The demand models used for calculating the shifts to feeder service were developed based on stated preference data only. In the absence of rational demand models developed based on either revealed preference data or a combination of revealed preference & stated preference data, it is assumed in the present work that all bicycle users will shift to feeder service provided that the feeder service is available within 2.0 km walking distance. A distance of 2.0 km is taken as threshold since in developing countries such as India, walking is the most common mode of travel for a distance of 1 to 2 km (Iles 2005). It may be mentioned that even the demand model used by Das et al. (2012) for bicycle users also indicated nearly 100 percent shift to feeder service for villages which are located on or within 2.0 km from the feeder route. The motorcycle users, who represent a negligible fraction of rural population, are not considered in the present work while calculating the ridership for feeder service. Das et al. (2012) considered two types of feeder vehicle namely 'Trekker' and 'Tempo'. In the present work, the role of fare model on feeder service is investigated taking only 'Trekker' as the feeder vehicle.

The design of feeder service is aimed to maximize the benefit to users while selecting route, headway of service and fare, giving due consideration to the operational viability of the service. In the present work, the benefit to users is calculated in terms of the reduction in 'Generalized Cost (GC)'. GC is used as a comprehensive measure of disutility and accounts for costs associated with walking, waiting, discomfort inside feeder vehicles and also the direct cost (or fare). A feeder route is aimed to serve rural population who are located in the catchment area of a bus stop. Therefore, one end of a feeder route is a bus stop, but the other end could be any of the villages located in the catchment area of the bus stop. The service characteristics and operational viability are also influenced by the route. Comparison of all possible routes is therefore, necessary for identifying the optimal route and service characteristics. The steps followed for identifying the optimal feeder service with respect to each bus stop are outlined below.

Step-0: Read Inputs

The road network connecting a bus stop and all villages in the catchment area of the bus stop is essentially a spanning tree. The major inputs required for the design of feeder service for a bus stop catchment area include present daily travel demand for each village, span of operation of feeder service, directional and temporal variation of demand, village settlements and their distance from bus stop as per the spanning tree road network, journey speed and cut-off revenue model, vehicle capacity under normal condition, vehicle capacity under congested seating, minimum layover time of feeder vehicles at each end, fare models, fare levels for each fare model, etc.

Step-1: Generate Arrival Times

Generate arrival times of passengers during different hours for each village (i.e. for travel from a village to the bus stop) and the bus stop (i.e. for travel from the bus stop to villages). All passengers at a village or the bus stop are arranged in ascending order of their arrival time. 10 such datasets are generated as the average results obtained from 10 simulation runs are used for identifying the optimal feeder service. For each dataset repeat Step 2.

Step-2: Select Feeder Routes

Generate all possible feeder routes for a bus stop catchment area. If there are 'n' villages in the catchment area of a bus stop then there are 'n' possible feeder routes with each of these villages as one end and the bus stop at the other end. If a village is not directly connected by the feeder route then transfer the demand for that village to the nearest connected node on the feeder route provided that the distance between the village and the nearest connected node is not more than 2.0 km. Otherwise, trip makers from that village are assumed to continue to use the present mode (i.e. bicycle) only. For each feeder route repeat Step-3 to Step-4.

Step-3: Generate Schedule of Service and Calculate Required Number of Vehicles

On the basis of the maximum directional link load during an hour, calculate the number of trips required to serve the hourly demand in the peak direction of travel. Accordingly, generate the schedule of the service for the peak direction of travel. Also, generate the schedule in the off-peak direction based on the schedule in the peak direction, journey time and the minimum layover time. Calculate the number of vehicles required for maintaining the service headway during the peak hour. The required number of vehicles is calculated based on service headway during the peak hour, route length, average journey speed, and layover time.

Step-4: Simulate Movement of Vehicles and Passengers

Start a trip as per the schedule. Process passengers (i.e. boarding and/alighting) at each stop on the basis of arrival time of passengers at the stop, arrival time of vehicle at the stop, and available vehicle capacity. Similarly, process all passengers for all the trips during the span of operation for both directions of travel. For all trips store data pertaining to walking distance, waiting time, distance travelled under congested seating, distance traveled using feeder service etc.

Step-5: Select Fare Models and Fare Levels

Three fare models are investigated in the present work. Also, for each fare model several fare levels are investigated to identify the optimal fare level for a fare model. For each fare models and fare levels, repeat Step 6.

Step-6: Calculate Total Generalized Cost to Passengers and Revenue Earned per Vehicle

For the selected fare model and fare level, calculate the total generalized cost to all passengers served during the span of operation of the feeder service. Also, calculate the average revenue earned per vehicle during the span of operation and check the operational viability of the service.

Step-7: Identify Optimal Service for Each Fare Model

For each fare model, consider all fare levels which produced operationally viable services. Select the optimal fare level i.e. fare level which produced operationally viable service with the lowest generalized cost to all passengers. Similarly, identify optimal fare levels for all the three fare models investigated in the present work.

3 INPUT DATABASE

Input database includes road network, vehicle characteristics (capacity under normal and congested seating, cut-off revenue and journey speed), minimum layover time, generalized cost model, travel demand etc. A brief description of various inputs is given below.

Road Network

The road network considered for design of rural feeder service is same as that developed under the rural road development program. Road network database includes length of each link and connecting nodes (i.e. village or bus stop).

Vehicle Characteristics and Cut-off Revenue

The work is demonstrated taking 'Trekker' as a feeder vehicle. The cut-off revenue i.e. the minimum earning required to cover the fixed cost, running cost and profit to the operator, is estimated as per Das et al. (2012). The estimated cut-off revenue for Trekker is given in Eq.(1)

$$CR_{(Trekker)} = 247 + 2.8 * d + P \quad \text{... (1)}$$

Where, $CR_{(Trekker)}$ is the required cutoff revenue per day in INR for Trekker, d is the distance traveled per vehicle per day in km and P is the minimum profit for operator per day in INR.

Journey Speed and Minimum Layover Time

Journey speed and minimum layover time are key inputs for the determination of minimum number of vehicles required to maintain the service headway during the peak hour. In the present work, journey speed is taken as 30 km per hour and minimum layover time is taken as 5 min at each end.

Generalized Cost Model

In the present work, GC is used as a comprehensive measure of disutility for travel and accounts for user costs associated with walking, waiting, discomfort inside feeder vehicles, discomfort using bicycles and also the direct cost (or fare). The generalized cost model used in the present work is obtained from Das et al. (2009) and Das et al. (2012) and given in Eq.(2).

$$GC = 0.5075*WD + 0.0723*TD + K*D + F \quad \text{...(2)}$$

Where, GC is the generalized cost to each passenger in INR, WD is the walking distance in Km, TD is the Time Deviation or waiting time at the stop in minute, D is the distance travelled under congested seating, and F is the direct cost or fare.

It may be mentioned that 0.5075 is the value of walking distance (in INR per km walking distance), and 0.0723 is the value of waiting time (in INR per minute). In rural India small vehicles (Tempo or Trekker) are found to carry more passengers than the seat capacity specified by manufacturer. Accommodating more passengers causes discomfort to passengers and the travel condition is described as 'congested seating'. When vehicles carry passenger only up to the seat capacity as specified by the manufacturer, the travel condition is described as 'comfortable seating'. K is to account for such discomfort due to congested seating and the value of K is 0.327 (in INR per km) under congested seating. The value of K is 0 when it is comfortable seating. For bicycle users, the value of K is 1.55 (in INR per km) which reflects the discomfort of traveling by bicycle. It may also be mentioned that for bicycle users Walking Distance (i.e. WD) and Time Deviation or Waiting Time (i.e. TD) are zero.

The values associated with walking distance, time deviation or waiting time, and congested travel were calculated by collecting stated preference data from rural commuters in the study area and analyzing the data using different econometric model specifications. The details of the work related to valuation of attributes of rural feeder service have already been reported in Das et al. (2007), Das (2008), Das et al. (2009), Das et al. (2012).

Fare Models

Three fare models are investigated in the present work. These are called as Fare Model-I, Fare Model-II and Fare Model-III.

Fare Model-I assumes a fixed fare rate as shown in Eq.(3).

$$F = X*R \qquad \text{... (3)}$$

Where, F is the fare in INR, X is the distance travelled in Km and R is the fare in INR per km.

For the fare model shown in Eq.(3), 11 fare levels are investigated by varying R from 0.5 to 3.0 with an increment of 0.25.

Fare Model-II assumes a fixed fare for all trips irrespective of trip lengths, as shown in Eq.(4).

$$F = F1 \qquad \text{... (4)}$$

Where, F1 is the fare in INR for all trip lengths.

For the fare model shown in Eq.(4), 10 fare levels are investigated by varying F1 from 0.5 to 5.0 with an increment of 0.5.

Fare Model-III is shown in Eq.(5).

$$\begin{aligned} F &= R1 && (\text{if } X1<X_{min}) \\ &= R1 + (X1 - X_{min})*R2 && (\text{if } X1>=X_{min}) \quad \text{... (5)} \end{aligned}$$

Where, R1 is the fare in INR for a distance upto X_{min} (in km), R2 is the fare in INR per km travel in excess of X_{min}.

For the fare model shown in Eq.(5), 500 levels are investigated by varying X_{min} from 2.0 to 4.0 with an increment of 0.5, and R1 & R2 from 0.50 to 2.75 with an increment of 0.25.

Travel Demand

Travel demand between each village and nearest bus stop is a key input for the work. It was necessary to model bus stop bound travel demand generated from various villages in the study area and capture the temporal variation of demand. In the present work, travel demand from each village is estimated using the trip rates reported by Das et al. (2012) for different categories of household. Das et al. (2012) classified households into three categories namely cultivator, daily labor and service/business and also estimated trip rates separately for revenue generating and non-revenue generating trips.

4 RESULTS AND DISCUSSION

The optimal feeder services for all the bus stop catchment areas are calculated and a comparison of the Generalized Costs (GC) for all bicycle trip makers located in different bus stop catchment areas is given in Table 1. Table 1 includes total GC for the three fare models (with feeder service) along with the present total GC (i.e. without any feeder service). The percentage changes in the GC for different fare models with respect to the present condition (i.e. without feeder service) are given in Table 2. It may be observed from Table 1 and Table 2 that for majority of bus stop catchment areas, the feeder service brings down the GC indicating benefit to the rural community due to feeder service. The results justify the need for developing an appropriate feeder service in rural India.

For Fare Model-I and III, feeder service is found beneficial for all the bus stop catchment areas, while for Fare Model-II feeder service is found beneficial for all the bus stop catchment areas except for Bhasra, Panchiyar and Syamalpur. From Table 1 and Table 2, it may be observed that for almost all the bus stop catchment areas, Fare Model-III produced higher benefits (i.e. lower GC) as compared to Fare Model-I and II. While in some cases Fare Model-II failed to produce any benefit to the commuters, Fare Model-I produced benefit in all the cases. Also, the benefits from Fare Model-I are found higher than those from Fare Model-II. It is obvious that while feeder service is generally expected to produce benefits to rural users, the amount of benefit is greatly influenced by the fare model. The selection of an appropriate fare model is therefore, an important task in the context of rural feeder service. In the present case study, Fare Model-III is found to enhance the benefit to the maximum.

For all fare models, the benefits are found to vary significantly across different bus stop catchment areas indicating that the benefit likely to be derived from feeder service is a function of the catchment characteristics such as location of villages, travel demands, road network, etc.

Table 1 A Comparison of Generalized Costs with and without Feeder Service

Catchment Area of Bus Stop	Without Feeder Service	With Feeder Service		
		Fare Model-I	Fare Model-II	Fare Model-III
Bhasra	11444	11106	12397	10958
Daihara	2764	2235	2556	2118
Dantan	7267	6574	7250	5700
Kalbani	4859	3933	4628	3657
Khokra1	4943	3833	4310	3625
Khokra2	2716	2014	2263	1996
Kukai	2495	2090	2295	2007
Monaharpur	5084	4728	5001	4382
Nachipur	1804	1436	1542	1371
Panchiyar	1830	1827	1992	1752
Salajpur	5208	4681	5103	4475
Sarisa	2147	1758	1987	1758
Syamalpur	1669	1661	1946	1589
Study Area	**54231**	**47879**	**53269**	**46015**

Note: Values in the Table indicate Generalized Cost in INR

Table 2 Percentage Savings in Generalized Cost with Feeder Service

Catchment Area of Bus Stop	Fare Model-I	Fare Model-II	Fare Model-III
Bhasra	3.0	-8.3	4.2
Daihara	19.1	7.5	23.4
Dantan	9.5	0.2	21.6
Kalbani	19.1	4.8	24.7
Khokra1	22.5	12.8	26.7
Khokra2	25.9	16.7	26.5
Kukai	16.2	8.0	19.6
Monaharpur	7.0	1.6	13.8
Nachipur	20.4	14.5	24.0
Panchiyar	0.1	-8.8	4.3
Salajpur	10.1	2.0	14.1
Sarisa	18.1	7.4	18.1
Syamalpur	0.5	-16.6	4.8
Study Area	**11.7**	**1.8**	**15.1**

Table 3 Percentage of Road Length Directly Served by Feeder Service

Catchment Area of Bus Stop	Fare Model-I	Fare Model-II	Fare Model-III
Bhasra	50.0	41.4	50.0
Daihara	72.1	75.0	72.1
Dantan	88.9	73.7	73.7
Kalbani	79.5	79.5	74.7
Khokra1	49.4	39.3	49.4
Khokra2	57.4	57.4	57.4
Kukai	43.6	56.4	56.4
Monaharpur	61.7	61.7	79.8
Nachipur	41.2	41.2	64.7
Panchiyar	80.4	37.5	37.5
Salajpur	74.0	49.0	74.0
Sarisa	31.4	31.4	31.4
Syamalpur	47.8	47.8	74.6
Study Area	**60.8**	**61.8**	**61.8**

For different fare models, the percentages of road length directly served by the feeder service are summarized in Table 3. It may be observed from Table 3 that while for some bus stop catchment areas the values are different, for some other bus stop catchment areas the values are nearly the same for different fare models. For the complete study area (i.e. catchment areas of all the 12 bus stops), the percentages of road length directly covered by feeder service is found as 61.8% for Fare Model-II and III. The value for Fare Model-I is 60.8% which is only marginally lower than the same for Fare Model-II and III. On the contrary, the benefits derived from Feeder Service are found to vary significantly (i.e. 11.7%, 1.8% and 15.1% for Fare Model-I, II and III respectively), indicating the importance of fare model in the context of rural feeder service. Table 3 also justifies the need for formulating strategies for covering more road length directly by the feeder service and thereby enhancing the benefit to rural commuters.

The fare levels for different fare models which produced optimal feeder services for different bus stop catchment areas are summarized in Table 4. It may be observed that for all the fare models, the optimal fare levels vary across different bus stop catchment areas indicating again the role of catchment characteristics in the context of rural feeder service. Table 4 also indicates that if it is aimed to optimize the feeder service for individual bus stop catchment area, then the fare levels for different feeder routes (or bus stop catchment areas) are likely to be different (i.e. differential fare level) even when all such routes are located in the same administrative block or district. A single fare level is expected to bring down the overall benefits to the rural community as compared to differential fare level. At present, feeder vehicles in rural India are owned and/or operated by individuals. Operating all feeder vehicles and routes in a geographical region (say, a block or a district) by a single organization (Private or Government) may be instrumental in covering more road length directly by the feeder service and enhancing the benefit to rural community with various types of subsidy. Such an operation may also be instrumental in operating different feeder routes with a single fare level without significantly bringing down the benefits to the rural population.

Table 4 Optimal Fare Levels for Different Fare Models

Catchment Area of Bus Stop	Fare Model-I	Fare Model-II	Fare Model-III		
	R^*	F^+	$R1^\$$	$R2^\$$	$X_{min}^{\$}$
Bhasra	1.25	3.75	1.50	2.00	3.00
Daihara	1.00	2.50	2.75	0.75	2.50
Dantan	1.25	3.25	1.25	2.00	4.00
Kalbani	1.25	3.00	1.25	2.00	3.50
Khokra1	1.25	2.25	1.25	2.50	2.50
Khokra2	1.25	2.25	0.75	2.75	3.50
Kukai	1.25	1.75	1.50	2.00	2.50
Monaharpur	1.25	2.75	2.75	1.00	2.00
Nachipur	1.25	1.50	2.50	1.25	2.00
Panchiyar	1.25	1.75	2.75	0.50	2.00
Salajpur	1.50	3.50	2.00	1.75	3.50
Sarisa	1.50	1.75	2.75	2.75	2.00
Syamalpur	1.25	2.00	1.50	0.75	4.00

* Refer to Eq.(3) + Refer to Eq. (4) $ Refer to Eq. (5)

5 CONCLUSIONS

With the recent improvement of roads in rural India, the design of a suitable feeder service between village settlements and bus stops has become a necessary task. Fare is one of the most important parameters in the context of rural feeder service. In the present work, a simulation based approach is applied for the design of rural feeder service with three different fare models. The work is demonstrated with reference to a case study in rural India. Feeder service is generally found to produce benefits to rural commuters for all the fare models. The benefit to rural population is measured using a comprehensive measure of disutility called as Generalized Cost (GC) which accounts for costs associated with walking, waiting, discomfort inside feeder vehicles and also the direct cost (or fare). The benefit to rural population justifies the need for developing an appropriate feeder service in rural India.

The benefit to rural population is found to vary significantly across three fare models indicating the importance of selecting an appropriate fare model for rural feeder service. In the present case study, a particular fare model (called as Fare Model-III) is found to enhance the benefit to the maximum. For all fare models, the benefits are also found to vary significantly across different bus stop catchment areas indicating that the benefit likely to be derived from feeder service is a function of the catchment characteristics such as location of villages, travel demands, road network, etc. For all the fare models investigated in the present work, the percentage of road length of the study area (i.e. catchment areas of all the 12 bus stops) directly served by feeder service is generally found to be the same. However, significant variation is observed in terms of benefits derived from feeder system in the study area with three fare levels. This also strengthens the importance of fare model in the context of rural feeder service.

The present work indicates that if it is aimed to optimize the feeder service for each bus stop catchment area, then the fare levels for different feeder routes (or bus stop catchment areas) are likely to be different (i.e. differential fare level) even when all such routes are located in the same administrative block or district. A single fare level for all feeder routes is expected to bring down the overall benefits to the rural community as compared to differential fare level. Further investigation is necessary for covering more road lengths directly by feeder service and enhancing the benefits to the rural community by addressing issue pertaining to organizational aspects of operating feeder service, fare level, subsidy, etc.

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