Journal of Physical Sciences, Vol. 10, 2006, 70 – 84

Energy Allocation in Rural Transport Using Fuzzy Optimization Techniques

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Received 26 December, 2006 ; accepted 31 December, 2006

ABSTRACT

Transport is one of the most important components of infrastructure so far as the growth process of an economy is concerned.. In this study, all the purposes of transportation are divided into two categories, one is passenger transport and other is goods transport. The distances are classified by seven groups for passengers and four groups for goods by distance covered. Diesel, petrol and human energy are used for passenger transport while animal energy, human energy and diesel are considered for goods transport. Minimization of total cost of direct energy, Minimization of non-local energy and Minimization of total time are the three objectives which are optimised under nine sets of real constraints. A compromised solution to all these three objective functions has been obtained by using Multi Objective Fuzzy Linear Programming (MOFLP) approach. The model is applied on the analysed data collected by primary and secondary survey from Narayangarh Block of West Medinipur District in the state of West Bengal in India. In transport sector, there is very little scope to alter the modes but to introduce new modes, this model has been found to quite effective in selecting origin, destination and distance ranges including intervening stoppage points.

Keywords : *Rural Transportation, Transport model, Multi Objective Fuzzy Linear Programming, Alternative Decision Making.*

1. Introduction

Escalation of cost of energy and its effects on economy is not new. With the conventional sources of energy being depreciated at a very fast rate and the demand for the same being grown at a hiking rate, the gap between energy demand and energy supply is more and more widened over the years. A system of improved transportation in any region makes resources available far and near, permits more extensive division of labour, extends the area of markets, promotes large scale production, stabilises prices and reduces total production cost. It has, therefore, a vital influence in the allocation of economic resources and advancement of regional economic efficiency. Thus transportation creates time and space utilities. The farmer, in all probability, produces his best, when he is assured of a handsome return on his investment through a system of smooth, continuous and safe transport of his produces to the market.

This is such a sector where alternatives are very few. The crux of the matter is that one has to deal with a complex system and try to understand the behaviour and dynamic response of the system which, because of its complex mode of reaction and of the interconnection and non-linearity of the effects, usually follows complex patterns that are difficult to predict.

Any transportation model is aimed providing an optimal solution subjected to minimization of costs and minimization of time. When such a model is applied for rural areas of developing countries, its needs to tackle other crucial objective like minimization of non-local sources of energy which has direct implication in social welfare. This calls for designing an appropriate scheme of energy supply-consumption model which can assure maximization of welfare to the rural mass on one hand and incorporate the effects of location specific factors depicting the needs and aspirations of the people on the other. The present paper attempts to build such an optimization model taking a Community Development (CD) Block i.e., intermediate level spatial sub-division of the three tier administrative system of rural India.

Narayangarh, the target CD Block of the country has been specifically selected for testing this micro-level energy planning model. This Block is located in the West Medinipur district of West Bengal State of India. It has 2,59,668 population in 463 habited villages with a net density 515 persons per square km. The dense clusters of settlements are located at the central part of the Block along the two arterial roads namely Belda - Narayangarh road and Belda - Dantan road.

Due to lack of data, complex mode of reaction and non linearity of the effects, this sector of rural system are rarely touched by the researchers. Gandhi in 1991 stressed on the importance of fuel management in road transport. Some researchers like Saxena (1975) have been analysed special cases of transport like agricultural transport etc and theoretically discussed about relation between transport and market. Most of the scholars have worked on other sectors of rural system using single objective function namely Minimization of cost. Since most of the decision problem are inherently multi objective, multi criteria decision problem is rapidly growing. Chetty & Subramanian ('88) first used multi objective Goal Programming to energy planning. However, Zimmerman (1978) suggests that for comparing different ways of action as to their desirability and for judging the suitability, the Minimization of surpluses over the aspiration levels of objectives may be maximized. To handle the exact but imprecisely known data, a fuzzy decision model may also be formulated (Jana 2001, Narshiman '80). Chedid ('99) and Jana & Chattopadhyay (2004) used Fuzzy Linear Programming for obtaining solution in multi objective planning.

2. Present Pattern And Nature Of Rural Transport

The principal subsystems characterising the transport system are infrastructure (roads, rails, ports, etc), transport means or vehicles (car, bus, train etc), service and organisation (management, personnel, control etc). Any scheme for the development of rural transport, however, presupposes knowledge about the transport needs of rural areas and their characteristics. The demand for transport is so universal that it would make redundant any exhaustive enumeration of the various purposes for which it is needed. From the transport point of view one can distinguish between passengers and goods. Though there is no clear-cut nodal division between passengers and goods, those are kept separate for the purpose of this analysis. The mixed passengers and goods case is not considered here, because it is of low importance and it is always convertible to any of goods or passenger traffic. The most important characteristic of rural transport is its small size and volume by urban standards. Almost all the traffic originating in rural areas are considered as variables both in regard to time and volume. Passenger traffic in the villages largely originates on social and religious occasions like marriages, fairs, festivals and community gatherings.

The inter-village and intra village traffic in goods and passengers is very negligible and even their movement to rural market is not very large. A big facility for these types of transport is bicycle, which is really a popular mode for short-distance transportation. For passengers, as a first subdivision one needs to separate individual mode of transportation (two-wheeler, car) from mass (bus, tracker etc) transportation. These two different modes usually correspond to two different types of management - private and public respectively. The distances covered by the people are also very complicated to measure. Here the distances are classified by 7 groups for passengers and 4 groups for goods in terms of distance traversed as shown in Table 1 & 2 respectively.

Table 1 : Demand for passenger transportation per year

K	Distance Range (km)	Average Distance traveled (km)	Demand per year (‘000 man)
1	Upto 5	3	3467.5
2	6-10	8	4562.5
3	11 – 15	13	237.5
4	16 – 20	18	2190
5	21 – 25	23	912.5
6	26 – 30	28	1533
7	More than 30	33	1460

Table 2 : Demand for goods transportation per year

K	Distance Range (km)	Average Distance covered (km)	Demand per year (‘000 ton)
1	Upto 10	5	73
2	10 – 20	15	255.5
3	20 – 30	25	511
4	More than 30	35	346.75

Passenger transport is divided into two categories - Intra-Block and Inter-Block transport. Again inter Block movement are of three types like (i) through traffic i.e., originating from places out side the Block and terminating out side the Block though moving through the Block, (ii) movement from the block to places out side and (iii) movement from places outside to the Block. But for all the cases only the distances covered within the Block are considered. The villagers usually do not use any mode for short distances i.e., under 5 km and walking or bicycle is the best mode for them to cover full or part of such distances, if so felt necessary, carrying some goods also with them. Dual modes are widely used by the people. From village to nearest bus stop, the villagers use trolley or two-wheeler to cover upto 5 km and then they use bus or tracker to reach the destination. Transport sector is heavily depended on oil. Though generally diesel, petrol and electricity are the major sources of energy for transport, in rural areas animal and human energy are largely used for transportation. _In this study, diesel, petrol and human energy (i= 1,2,3) are considered as sources for passengers transport while animal energy (for bullock cart) along with the human energy and diesel (i= 4,3,1) are taken for goods transport.

3. Structure of the Model

The transport policy should aim at meeting the needs of the economy with the minimum demands on sources so that the movements of passengers and goods are executed at the minimum possible real cost within a minimum possible time. A systematic arrangement of speedy transport is, therefore, an essential prerequisite for the faster economic development of the regions and of the country. So in the present analysis, the Minimization of total cost and Minimization of total time of transportation have been the two major objectives of the model. Besides, another objectives namely, Minimization of non-local sources is also considered as important objectives in the task of energy allocation for rural transportation. However, to assure the effects of all the three objective functions on energy allocation, a compromised solution in a Fuzzy environment has been considered to be useful.

Nomenclature

x^p_{ijk} : Number of passengers in thousands traveling kth class of distance using ith source through jth mode of transport.

x^g_{ijk} : Tons of goods carried over kth class of distance using ith source through jth mode of transport.

C^p_{ijk} : Cost of travel for thousand passengers over kth class of distance using ith source through jth mode of transport.

C^g_{ijk} : Cost of transport per ton of goods over kth class of distance using ith source through jth mode of transport.

E^p_{ijk} : Energy required for thousand passengers traveling over kth class of distance using ith source through jth mode of transport.

E^g_{ijk} : Energy required for transport of goods per ton over kth class of distance using ith source through jth mode of transport.

T^p_{ijk} : Time required for thousand passengers to travel over kth class of distance using ith source through jth mode of transport.

T^g_{ijk} : Time required for transport of goods per ton over kth class of distance using ith source through jth mode of transport.

D^p_k : Demand for travel over kth class of distance in thousands of passengers.

D^g_k : Demand for transport over kth class of distance in tons of goods.

A^p_{ij} : Available capacity in passenger-km using kth source through th mode of transport

A_{ij}^{g} : Available capacity in passenger-km using *i*th source through *j*th mode of transport

M_{k}^{p} : Maximum km traveled by any passenger for *k*th class of distance.

M_{k}^{g} : Maximum km traversed by any consignment of goods for *k*th class of distance.

d_{k}^{g} : Demand of goods in tons to be transported by originating and terminating external traffic covering small distance in the Block (where k = 1 and 2) by truck or tractor or mini truck.

A_{j}^{p} : Availability of trips of *j*th mode for passenger transport in a year

A_{j}^{g} : Availability of trips of *j*th mode for goods transport in a year

Q_{j}^{p} : Average number of passenger can travel at a time through *j*th mode

Q_{j}^{g} : Average quantity of goods can travel at a time through *j*th mode

A_{i} : Availability of the source i

Objective Functions

The mathematical form of the objective functions are:

Objective-1: Minimization of Total Cost of Direct Energy

$$O_1 = \sum_i \sum_j \sum_k C^p{}_{ijk} x^p{}_{ijk} + \sum_i \sum_j \sum_k C^g{}_{ijk} x^g{}_{ijk} \quad (1)$$

Objective-2: Minimization of Non-Local Sources of Energy

$$O_2 = \sum_i \sum_j \sum_k E^p{}_{ijk} x^p{}_{ijk} + \sum_i \sum_j \sum_k E^g{}_{ijk} x^g{}_{ijk} \text{ for } i = 1 \text{ and } 2 \quad (2)$$

Objective-3: Minimization of Total Time

$$O_3 = \sum_i \sum_j \sum_k T^p{}_{ijk} x^p{}_{ijk} + \sum_i \sum_j \sum_k T^g{}_{ijk} x^g{}_{ijk} \quad \forall\, i,\, j,\, k \quad (3)$$

Constraints

The above Objective functions are optimized subject to the following sets of constraints.

$$\sum_i \sum_j x^p{}_{ijk} = D^p{}_k \qquad \forall\ k \quad (4)$$

$$\sum_i \sum_j x^g{}_{ijk} = D^g{}_k \qquad \forall\ k \quad (5)$$

$$\sum_k M^p{}_k x^p{}_{ijk} \le A^p{}_{ij} \qquad \forall\ i,\ j \quad (6)$$

$$\sum_k M^g{}_k x^g{}_{ijk} \leq A^g{}_{ij} \qquad \forall\ i,\ j \qquad (7)$$

$$\sum_i \sum_k \frac{x^p{}_{ijk}}{Q^p{}_j} \leq A^p{}_j \qquad \forall\ j \qquad (8)$$

$$\sum_i \sum_k \frac{x^g{}_{ijk}}{Q^g{}_j} \leq A^g{}_j \qquad \forall\ j \qquad (9)$$

$$\sum_i \sum_j x^p{}_{ijk} \geq d^g{}_k \qquad \text{for } j = 1 \text{ and } 2 \quad \text{and} \quad k = 1 \text{ and } 2 \qquad (10)$$

$$\sum_i x^g{}_{ijk} \geq d^g{}_k \qquad \text{for } j = 1 \quad \text{and} \quad k = 3 \text{ and } 4 \qquad (11)$$

$$\sum_i \sum_j \sum_k E^p{}_{ijk} x^p{}_{ijk} + \sum_i \sum_j \sum_k E^g{}_{ijk} x^g{}_{ijk} \leq A_i \qquad \text{for } i = 1 \text{ and } 2 \qquad (12)$$

4. Method of Solution

The three objective functions (1) to (3) can be solved one after another subject to the sets of constraints (4) to (12). While solving any single objective function independently, the values of other objective functions may largely deviate from their respective optimum values obtainable. The maximum deviation creates the aspiration level of corresponding objective function. This calls for attaining a compromised solution incorporating all the constraints (4) to (12) and simultaneously introducing the three additional constraints depicting the aspiration levels of three objective functions. The Multi Objective Fuzzy Linear Programming (MOFLP) is such a technique that can tackle this exercise.

Let x^1, x^2 and x^3 represent the set of solutions for the objective functions O_1, O_2, and O_3 respectively.

Thus $U_t = Min(O_t(x^t))$ and

$L_t = Max(O_t(x^t))$ for $t \neq s$

Where U_t and L_t indicate most and least acceptable values for tth objective function respectively.

Then μ_t the membership function of tth objective is defined by

$$\mu_t = 0 \qquad \text{when} \quad O_t \geq L_t$$

$$= \frac{L_t - O_t}{L_t - U_t} \qquad U_t \leq O_t \leq L_t$$

$$= 1 \qquad O_t \leq U_t$$

Now a dummy variable l is introduced for fuzzy solution such that $l \le m_t$, $\forall t$
So 3 more constraints have been formed with these aspiration levels.
Then Fuzzy Linear Programming (FLP) becomes
Maximize l

Subject to :

$O_t + (L_t - U_t)\, l \le L_t$

$l \ge 0$ And all other constraints used in individual objectives including non-negativity of decision variables.

Then, applying the Simplex method the above problem is solved where all the objectives are considered together with the initiated 9 sets of constraints to achieve a best compromised solution.

5. Information

In the study area, bus services are very frequent but average distance from the village to nearest bus stop is more than 5 km which is traversed by some other modes like trolley or rickshaw or two-wheeler. Some villagers who are staying at a distance of more than 10 km far from the bus stop usually avail tracker though such facility is very few in the Block. In spite of the existence of two railway stations in the Block the villagers hardly use railway service. During survey it is seen that hardly 10-15 persons per day are either coming in the Block from out side or going out from the Block. It may be mentioned here that walking, bicycles and railway services are not considered in present study. The traffic survey has been done at all the bus stoppages together information on mode, demand, frequency etc and other relevant data are obtained from household survey. For passenger and goods transportation, the estimated availability of modes and their carrying capacities are given in Tables 3 and 4 respectively.

During the traffic survey in Narayangarh Block, the trip purposes like movement for marketing, fair and festivals, litigation, visit to administrative and development offices, academic institutions and miscellaneous other purposes have been identified. Market is such a place from where the facilities for both passenger and goods transports are required.

Table 3 : Availability of passenger transportation modes

Name of the Mode (j)	Number of Available Modes	Number of Trip per day	Average Passengers can travel at a time	Maximum Distance (km) can travel within the CD Block	Total Availability Per year ('000 man-km)
Bus (1)	75	2	80	35	153300
Tracker (2)	10	4	15	20	4380
Petrol Taxi (3)	30	2	5	35	3832.5
Diesel Taxi (4)	70	2	5	35	8942.5
Trolley (5)	600	2	4	10	17520
Rickshaw (6)	150	4	2	10	4380
Two-Wheeler (7)	7200	2	1	20	2628

Table 4 : Availability of goods transport modes

Name of the Mode (j)	Average Number of Availability	Number of Trip per day	Average Quantity of Goods (ton) can be transported at a time	Maximum Distance (km) can be traversed within the CD Block	Total Availability per year ('000 ton-km)
Truck (1)	220	1	6	40	19272
Tractor and Mini Truck (2)	28 +100	1	4	40	6736
Trolley (3)	400	2	0.5	20	2400
Bullock Cart (4)	8900	1	1.5	20	26700

In this study area as many as 28 rural markets (Hats) are functioning. People are coming from the surrounding areas traversing a distance upto 15 km to sale or purchase various commodities. Most of the Hats are periodic i.e., functioning one or two days a week. Besides, small daily markets in the important growth centres are also surveyed. Another important purpose for which transport facilities are needed in this rural area is the movement of forest produces from the places of collection to the places of selling.

For obtaining solutions, the unit costs by modes and distance ranges for passengers and goods transport have been collected through primary survey (Tables 5 and 6).

Table 5: Cost incurred per passenger to different distances through different modes of transport

Mode	Mileage per unit fuel	Distances (km)						
		Below 5	5 - 10	10 – 15	15 - 20	20 - 25	25 - 30	Above 30
Bus	3	2	3.5	6	8.5	11	13.5	16
Taxi	8	*	*	*	*	20.7	25.2	29.7
Tractor	25	3	4	5	6	*	*	*
Two-Wheeler	45	4.40	11.72	19.045	26.37	*	*	*
Trolley	12	4	8	*	*	*	*	*
Rickshaw	12	4	10	*	*	*	*	*

* Not Applicable

Table 6 : Cost incurred to transport one ton of goods to different distances through different modes.

Mode	Mileage km per unit fuel	Distance (km)			
		Below 10	10-20	20-30	Above 30
Truck	3	25	75	125	175
Mini-Truck / Tractor	4	31.25	93.75	156.25	218.75
Trolley	10	60	100	*	*
Bullock Cart	4	60	100	*	*

* Not Applicable

Similarly, the time units spent for covering different distance slabs by different passenger and goods transport modes have been obtained and shown in Tables 7 and 8.

Table 7 : Time required (minutes) for different modes of passenger transport in different distances.

Mode	Distances (km)						
	Below 5	5 – 10	10 - 15	15-20	20 - 25	25 - 30	Above 30
Bus	6	15	22	30	40	55	65
Taxi	*	*	*	*	35	45	60
Tractor	8	20	35	50	*	*	*
Two-Wheeler	5	12	20	30	*	*	*
Trolley	15	40	*	*	*	*	*
Rickshaw	15	40	*	*	*	*	*

* Not Applicable

Table 8 : Time required (minute) for different modes of goods transport in different distances

Mode	Distance (km)			
	Below 10	10-20	20-30	Above 30
Truck	7	20	35	50
Mini-Truck / Tractor	10	30	50	70
Trolley	30	90	*	*
Bullock Cart	75	225	*	*

* Not Applicable

6. Results and Discussions

The solution to the model has highlighted 4 alternative results of which 3 are responsive to three individual objective functions and the other one is a compromised solution to the above objectives obtained through application of MOFLP technique (Table 9 and 10). From the results it is seen that the available source of bus services is totally exhausted and has got preference in solutions to all the objectives.

Table 9 : Source utilization pattern for passenger (in ’000 man) transport in narayangarh block

Objectives	Distances (km) Mode	Below 5	5-10	10-15	15-20	20-25	25-30	Above 30
Minimization of total Cost	Bus	1314	2372.5	2372.5	12.17	912.5	1533	1072.9
	Taxi (Petrol)							116.14
	Taxi (Diesel)							271
	Tracker				243.33			
	Two-Wheeler	693.5			1934.5			
	Trolley		2190					
	Rickshaw	1460						
Minimization of Non-Local Energy	Bus	3467.5	489.1	2372.5	350.4	745.87	1303.6	1460
	Taxi (Petrol)					166.6		
	Taxi (Diesel)						229.4	
	Tracker		547.5					
	Two-Wheeler		788.4		1839.6			
	Trolley		2190					
	Rickshaw		547.5					
Minimization of Total Time	Bus		2892.6	795.7	1138.8	357.06	1533	1460
	Taxi (Petrol)					166.6		
	Taxi (Diesel)					388.8		
	Tracker		547.5					
	Two-Wheeler			1576.8	1051.2			
	Trolley	2847	1122.4					
	Rickshaw	620.5						
Fuzzy Model	Bus	2007.5	2363.8	356.89	1334.3	370.5	1533	1460
	Taxi (Petrol)					166.63	11.47	
	Taxi (Diesel)					375.4		
	Tracker		8.64		239.5			
	Two-Wheeler			2018.8	609.14			
	Trolley		2190					
	Rickshaw	1460						

The optimum solution to objective 1 i.e., Minimization of total cost for passenger transport reveals that besides bus service, the use of rickshaw and two-wheeler is suitable for below 5 km range. For 5 to 10 km range, the cycle trolley appears to be the most preferred mode. Tracker and two-wheeler services are most suitable for 15-20 km distance range and choice of taxi service seems to be the best for distance above 30 km.

Considering goods transport, the optimum solution to first objective indicate that cycle trolley is the most suitable mode for any distance below 20 km while bullock cart is best for 10 to 20 km distance range. Tracker and mini trucks have been observed to be most preferred for distance above 20 km. Truck service appears to be the chosen mode for all distance slabs particularly above 20 km.

Table 10 : Source utilization pattern for goods (in ’000 ton) transport in narayangarh block

Objectives	Distances (km) Modes	Below 10	10-20	20-30	Above 30
Minimization of total Cost	Truck	27.35	64	482.01	175
	Tractor/Mini Truck			29	171.75
	Trolley	45.65	144.78		
	Bullock Cart		46.72		
Minimization of Non-Local Energy	Truck		21.68	511	175
	Tractor/Mini Truck	18	42.3		171.75
	Trolley	55	141.67		
	Bullock Cart		49.8		
Minimization of Total Time	Truck		67	485.61	175
	Tractor/Mini Truck	18		25.39	171.75
	Trolley	55	141.67		
	Bullock Cart		46.7		
Fuzzy Model	Truck		64	511	175
	Tractor/Mini Truck	27.35			171.75
	Trolley	45.65	144.78		
	Bullock Cart		46.7		

The solution to Minimization of non-local sources of energy (Objective 2) shows that rickshaw, cycle trolley and tracker are most preferred modes for 5-10 km only whereas two-wheeler is preferred for the distance range of 5-10 km and also 15-20 km . Taxi and cars are most suitable modes for 20 to 25 km and 25 to 30 km distance slabs through use of petrol and diesel respectively.

For goods transport, cycle trolley is most suitable for distance below 20 km whereas the service of bullock carts is most preferred for 10 to 20 km only. Tractor or mini-truck service seems to be the best source for distance below 20 km or above 30 km while trucks are most effective for any distance more than 10 km.

It is observed that for Minimization of total time (i.e. objective 3), the bus as a mode is not suitable for the distance range below 5 km. In respect of passenger transport, it is revealed that cycle trolley is viable for distance below 10 km while rickshaw is suitable for below 5 km range only. Taxi and car services are suitable for 20-25 km range of distance irrespective of operation through use of petrol or diesel. Trackers seem to be effective for 5 to 10 km range of distance. Two-wheelers share minimum system time if used for 10 to 20 km range of distance.

For goods transport, the solution to the above objective indicates that cycle trolley can be used with preference for distance below 20 km and bullock cart for 10 to 20 km. Trackers or mini trucks are most suitable for distances more than 20 km and below 10 km whereas trucks can be used for distances more than 10 km.

If decision-makers try to minimize the total cost only, then total time would increase as a consequence. Similarly, to get optimum solution for attaining any individual objective, the resultant values in respect of other objectives increase. Table 11 shows the sets of values corresponding to each objective. Considering the solutions to all the objectives, it is seen that the difference between the minimum cost and maximum cost stands approximately at Rs. 40 lacks. Similarly, the differences between the minimum and maximum values in respect of non-local energy and total time are 3693 GJ and 7696 thousand minutes respectively.

Table 11 : Comparative solutions for the objectives of the model

Solution	Obj-1	Obj-2	Obj-3	Fuzzy
Total Cost (Rs. '000)	323896.4	327865.4	327446.5	324855.4
Non-local Energy(GJ)	172546.5	171551.5	175244.9	172441.6
Total Time (Thousand minutes)	148460.5	150676.9	142918.3	144793

Under such circumstances, the approach towards a composite solution with all the objectives under fuzzy environment would definitely offer the most compromised solution to this multi-criteria problem. In the current solution, the compromised values of all the objective functions have been observed to stand at 75.8% compromised levels for all objectives.

Bus service is found to be suitable for all the distance ranges in this MOFLP solution. Tracker is suitable for 5 to 10 km and 15 to 20 km whereas cycle trolley and rickshaw are preferred for 5 to 10 km and below 5 km distance ranges respectively. Petrol fueled taxi and cars will be most suitable for 20 to 30 km range while diesel taxi and cars is most favoured for 20 to 25 km distance range. In this solution, two-wheelers are shown to be optimally used for the distance slab 10 to 20 km.

The compromised solution for goods transport indicate the options of distance range for cycle trolley and bullock carts to be favourable at 0 to 20 km and 10 to 20 km respectively. Tractors and mini trucks are most preferred for below 10 km or more than 20 km distance ranges, but trucks are most effective only for the distances above 10 km.

7. Conclusions

In transportation system, there is very limited scope for altering the transport modes identified for different distance ranges in the above solutions. But for introducing new modes like tracker, bus or truck, this model will be of immense help in selecting origin and destination, entry point and exit point, distance ranges including intervening stoppage points. The solutions to all the decision criteria confirm the preconceived motive of gradually diminishing trend of bullock cart use which is further corroborated from the fact that less than 1000 bullock carts are currently in use though as many as 8900 carts are available for carrying goods in the villages. In fact, bullock carts are largely replaced by cycle-trolleys and tractors. Though the model appears to be quite flexible from the point of view of sources of energy use, the decisions in terms of minimum cost, minimum time, minimum non-local sources or even the compromised one are mostly tackled by the interplay of substitution of different modes since for rural transportation purposes the source-mode combinations are mostly unalterable.

Acknowledgement

The author is thankful to Department of Science and Technology (DST), Govt. of India for their financial support under SERC FAST Track scheme for the work. Vide sanction number SR/FTP/ET-148/2001 dated 05.05.2003.

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