CHAPTER 7

PUBLIC TRANSPORT COMPOSITION MODEL FOR CALCUTTA

7.1. Introduction

In this Chapter, we are in a position to formulate transport model for our study area, which has been investigated in-depth in the previous two chapters. The in-depth investigation is essential to diagnose typical problems and peculiarities of public transport in the study area and also to visualise the domain of model variables so as to avoid the frequent dangers of landing on to practically infeasible solutions. In our study, for example, we have observed the steady nature of fleet strength of the CTC, which was fairly constant at the level of 438 trams up to the year 1985-86 and after this the total number of trams suddenly dropped down to 398 and the same number is still continuing. A large number of tram cars have already got too old to provide service and the CTC are planning for their replacements and/or renovations, which itself is a high capital programme for the organisation, who are struggling hard even for their own existence. Once this scenario is exposed vividly to the planner, she or he would think enough before planning optimistically to put more fleet of tram in the city for travel improvements.

Similarly, we have experienced that most of the transport parameters have space variabilities, even in a
single city. Operating speeds, fuel usage rates, revenue rates, mode choice factors etc. vary significantly in different locations of the city. Hence the idea of model building with average or aggregate values of parameters, becomes unrealistic. On the other hand, using space as an independent variable, general travel equations or relationships amongst the model variables may be attempted. But this will lead to very complex situations, difficult for the analyst to work with. Operationally, these attempts may be supported but questions remain as to whether such an attempt fulfills the overall criteria of efficiency and equity, because as the model gets more generalized and sophisticated, it becomes difficult to solve and very often calls for assumptions, which distort the situation and the model moves away from the original problem. These aspects have already been discussed in the Chapter 2.

In order to ease the situation, one may think in terms of a number of local micro-level models, which may be compiled or summed up in a clever way in order to achieve the macro solution for the city as a whole.

7.2. Basic approach

Here our purpose is somewhat different. In this context, we do not propose to develop a comprehensive theoretical construct or model. We shall rather adapt a pragmatic view which is undoubtedly an important aspect of the conventional
As pointed out in the Chapter 2 that the conventional demand oriented models which are often used in transport planning in Developed countries, have serious limitations in their applications in the context of cities of Less Developed Countries, specially in a study area like that of ours. Here a system of public transport has evolved over the years and closer examinations of its history of its development revealed that several attempts have been made within the extremely restricted confines to improve the operating efficiency of the system. Practically if one takes into account all the physical and socio political constraints as given, that is almost unalterable, then we are left with no alternative, except to admit that the existing system is at least quasi-optimal. This is probably further justified by its prolonged existence and acceptance without much change over the time.

If such is the situation, then perhaps it is not possible to find an alternative viable as well as acceptable solution, within the given periphery of the system. What can be done in this context is to improve the operational
efficiency of the system by minor changes and adjustments of the system.

In the study area of Calcutta, the entire supply of different public transport is virtually regulated by government agencies, directly or indirectly. The governmental departments and agencies, for example Road Transport Authorities, Public Vehicles Department, Calcutta Corporation, etc. have somewhat indirect control over the system through licensing route permits to vehicles, introducing new routes or abolishing the existing ones, etc. Also the CTC and CSTC are public sector bodies, which operate vehicles and provide transport services, by acting directly in the system. This being the situation, we see that the supply side is rather as control variable and though relatively inelastic because of 1) financial stringencies of suppling agencies, 2) physical constraints of town planning, and 3) beaurocratic decision making, yet, supplies of different transport modes are the policy-variables in the hands of the policy makers.

7.3. Nature of Demand

Let us now turn into the demand aspects of our implicit model. As we have discussed at length in the previous chapters, that nature of aggregate travel demand and its characteristics in the context of our study area has been explored through some secondary records and mainly through primary surveys and traffic counts.
Investigations revealed the following facts:

1. Aggregate travel demand has a positive long term trend. But the slope of the trend is reducing sharply (as discussed in the Chapter 4) indicating saturation and only marginal demand increase in the city over the future years.

2. Considering the short-run period and local demands,
   a) Volumes of aggregate travel demands vary significantly with space and time.
   b) Given a location and a time-span of the day, nature of aggregate travel demand may be assumed to be stable for any week-day (in Chapter 5 the demand data showed low standard deviations at given locations and time intervals). The reason is because most of the travels in the city are production oriented and hence regular in nature. As the city has been moderately saturated, not much increase in the travel demand is expected over the time in the short run.

7.4. The Model

Considering all the phenomena as described above, we may assume that for our study area, at any location travel demand is given and its time rate of distribution is also a stable factor, at least in the short run. This is, therefore, the implicit model of our empirical exercise. In this model we confront a situation, where demand is a stable function of its relevant variables and the supply
is relatively an inelastic function, where the responsibility of adjustment lies on the supply side.

![Conceptual Frame work of The Implicit Model](image)

Now, at a particular location, the aggregate travel demand and its time distribution over the day is a given datum. Similarly, the existing Modal composition at the location with its time distribution is also fixed, as the number of vehicles of each mode on given routes is roughly stable. Since the system is at work, it means that there is a solution and for obvious reason, such a solution is a feasible one, leaving no room apparently for excess travel demand and excess supply of capacity. If so, then there is no point in searching for a better solution for the system. But this is not true in our case. A given supply capacity may meet the given demand, but the quality of services and other transport objectives, rendered by the system, may be extremely unsatisfactory. As discussed in the Chapters 2 and 3, just to move passengers from one point to the other is not the sole purpose of a transport system. An efficient and socially acceptable transport system must possess the qualities, which
satisfy the overall objectives of the public transport system.

In Chapter 3 we discussed the concept of Transport Performance Levels, which are possible outcomes of any transport system. There we explored an exhaustive list of components of such transport outcomes, appropriate to the cities of Less Developed Countries. It was also experienced that the types of transport performances or the outcomes fall under three broad categories, namely Service, Operating and Social and these may be considered to constitute the overall objective of a transport system in a city. A transport system may be considered as a satisfactory one, if the (1) levels of service of transport modes are satisfactory, (2) efficiencies of operation of the modes are satisfactory and (3) it satisfies a number of social criteria such as accident rate, energy consumption rate, employment rate, etc., as elaborated in the Chapter 3. The detail study on evaluating the transport performance levels of the modes of our interest has been made and summarised in the Chapters 5 and 6. From the study it was observed that performance levels of these modes vary among themselves. Also it is interesting to notice that even for a single mode, some of the parameters vary with space significantly. For example, operating speed, irregularity index, frequency, rate of fuel usage, occupancy rate, etc all have significant bearing on location of the city.
Now, in case of a micro-level model, which considers only a single location in the city, the local values of the attributes for individual mode may be considered. The overall performance at the location is just the aggregated performance of these modes. It may be pointed out, that making an adjustment on the supply composition of the transport modes, a variation in the overall performance levels may be obtained. Thus our attempt should be such that we should look for some suitable supply mix, for which the overall performance levels would be most satisfactory. The mathematical formulation of the model may be expressed as follows:

Let us consider that at a particular location (or link) of the city, the composition of public transport that exists, be described by the vector

\[ X^0 = x_1^0, x_2^0, x_3^0, \ldots, x_M^0 \quad \ldots (1) \]

where \( x_m^0 \) is the existing activity level in term of number of allotted vehicles, which are supposed to pass through the link, in case of the mode \( m \). Also let us assume that there are \( M \) different modes in the system.

Let us now define the existing objective function of our problem, given by

\[ z^0 = C^T X^0 \]

\[ = \sum_i \sum_j c_{ij} \cdot x_i^0 \quad \ldots (2) \]

where \( j=1, \ldots, n \) the number of parameters in terms of
transport performances or outcomes.

\[ c_{ij} \] is the level of performance of type \( j \) for
the mode \( i \). This may also be thought of as
per unit of outcome for the attribute \( j \) and
mode \( i \).

Now, since the different attributes are measured on
different scales and cannot be easily converted to a
single common scale, the equation (2) cannot be summed
up over \( j \).

Thus we have, for any composition \( X \),

\[ Z = \begin{bmatrix} T_1, T_2, \ldots, T_n \end{bmatrix} \quad \ldots \quad (3) \]

where \( T_j = \sum_i c_{ij} x_i \), the contribution for \( j \)th
outcome.

The empirical importance lies in estimating for each
attribute, the 'Per unit outcome' of the activities
\( x_1 \ldots x_m \), i.e., \( c_{ij} \), for \( \forall \quad i = 1, \ldots, m \)
\( j = 1, \ldots, n \).

Then, we may argue that any composition of transport
modes, say \( X \) would yield an outcome Vector \( Z \) with size \( n \),
where \( n \) is the total number of attributes. The rela-
tionship given by

\[ X \rightarrow Z \]

It may be assumed that there is one to one relationship
between \( X \) and \( Z \). Thus, the relation \( X \rightarrow Z \) may be
assumed to be reversible.
It is the objective of the exercise that we choose such a $Z$, which is optimal (Say $Z^*$) and the corresponding composition (Say $X^*$) is the optimal solution to the problem.

7.5. The detail structure of the composition model

The model as defined and described in the previous sections, may be illustrated by the following structural diagram:

```
Imposed constraints

Domain of supply

(Static Parameters)

(Dynamic Modal Demand Model) → Simulated Modal Split → Evaluation → Accepted Composition

(Static Parameters)

(Demand Pattern)

(Supply alternative)

(Control variable)

(Imposed constraints)

(Demand Pattern)

(Uncontrolled variables)
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The domain of supply of public transport is restricted by imposed constraints such as financial shortages, traffic volumes, lack of terminal facilities, etc. A supply alternative in terms of a composition of transport modes, may be chosen from the given domain. The demand, which is assumed to be given and fixed, will interact with the supply composition and the corresponding model split may be simulated using the regression relationships, as
established in the 'dynamic modal demand model' in Chapter 6. The mode performance levels, which are in fact the $c$ values of the model, are assumed to be static in the process. This assumption should be valid if the system is thought to be free from any external input, which augments the values of performance parameters of individual mode. For example, introduction of better managerial skill in the CSTC may improve values of many performance parameters such as, fleet utilization, cost reduction, better fuel usage, etc. But here we assume that during the process no such measures are applied to any of the components of the system, leaving the values of performance parameters to be the same as the existing values.

By using the information of supply mix, modal split and the mode performance level values, it is possible to compute $Z$ vector, which expresses the aggregate or weighted average values of transport outcomes for the given modal composition $X$.

It is clear that a set of possible alternatives, i.e., a set of $X$ vectors would produce a corresponding set of $Z$ vectors, and finally there is a requirement of evaluation of the $Z$ vectors in order to identify the best set of outcomes and hence the best $X$ can be chosen. If we consider $p$ such alternatives, then our model becomes the following:
Let there be \( k = 1, 2, \ldots, K \) routes in the city. We are interested in a micromodel at the link 1, such that only the routes for which
\[ k \in I \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 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Let \( r_{ml}^k \) be the average number of round trips conducted by each vehicle of mode \( m \) in route \( k \) per day, then the total trips conducted by all vehicles of mode \( m \) in all routes,

\[
R_m = \sum_k r_{ml}^k \cdot E_{ml}^k 
\]

(4)

Hence one way average hourly frequencies for mode \( m \) in all routes are given by

\[
F_m = \frac{R_m}{H_m}, \quad \text{for} \quad m = 1, \ldots, M
\]

(5)

where \( H_m \) is the daily service hours rendered by mode \( m \).

Thus the hourly passenger capacity offered by the mode is given by

\[
B_m = F_m \cdot a_m
\]

(6)

where \( a_m \) = capacity per vehicle of mode type \( m \)

Now let us suppose aggregate travel demand on the link under our consideration, has a time distribution over the whole day and is composed of \( Q \) number of time intervals. It is assumed that volumes of demand vary in each interval. Let \( D_1, D_2, \ldots, D_Q \) be the hourly aggregate demand volumes in a single direction of the link at each of the intervals. Then at any interval, say \( q \), the overall load factor may be expressed as

\[
\]

1. In the experiment the crush capacities were considered. The values of these capacities for the transport modes, have been given in the Chapter 6.
Load factor of individual mode, is however, dependent on some independent variables such as, Hourly demand, Overall load factor, Capacity shares of individual modes, etc. as we have established with regression models in Chapter 6. Thus, given the independent variables as stated, the modal load factors may be estimated with suitable regression equations of the form

\[ L_m = A_0 + b_1O_q + b_2D_q + b_3B_m' + b_4B_m'' + \ldots \]  

(8)

where \( L_m \) is the percent load factor of mode \( m \) and \( B_m' \) is the percent capacity share of mode \( m \) in the mix and is given by

\[ B_m' = \frac{B_m}{\sum B_m} \times 100 \]

(9)

Hence the number of passengers, carried by mode \( m \), during the time interval \( q \), is given by

\[ Y_{mq} = \frac{L_m}{100} \times B_m \times W_q \]

(10)

where \( W_q \) is the width of the interval \( q \) in hours.

Hence for the whole day, in the single direction the total passengers carried by mode \( m \) is give by

\[ Y_m = \sum_{q} Y_{mq} \]

(11)
If similar parameters are known for the opposite direction of the link, then the total passengers carried by the mode $m$ during the whole day in the other direction may be estimated following the same procedures, and let us call it $Y'_m$.

Thus total passengers per day by mode $m$ is given by

$$Y_m = Y_m + Y'_m$$

(12)

The key attributes which may be considered in the study for decision making purposes, may be evaluated using the following relationships:

1. Average fleet utilization including all modes, given by

$$U_1 = \frac{\sum_m \sum_k E_{ml}^k}{\sum_m \sum_k A_{ml}^k}$$

(13)

2. Average daily kilometers including all modes, given by

$$U_2 = \frac{\sum_m \sum_k E_{ml}^k \cdot d_{mk}}{\sum_m \sum_k E_{ml}^k}$$

(14)

where $d_{mk}$ is the daily kilometerage made by a single vehicle of mode $m$ on the route $k$. 

3. Average irregularity per trip, including all modes, given by

\[ U_3 = \frac{\sum_{m} R_m \cdot i_m}{\sum_{m} R_m} \]  

(15)

where \( i_m \) is the irregularity index for the mode \( m \).

4. Average per passenger journey speed at peak-hours, including all modes, given by

\[ U_4 = \frac{\sum_{m} Y_{mq} \cdot S_{mq}}{\sum_{m} Y_{mq}} \]  

(16)

for \( q' = \text{peak hour interval} \)

where \( S_{mq} \) is the operational speed of mode \( m \) in the peak-hour time interval.

5. Average fare per passenger, is given by

\[ U_5 = \frac{\sum_{m} \overline{V}_{m} \cdot f_m}{\sum_{m} \overline{V}_{m}} \]  

(17)

where \( f_m \) is average fare of mode \( m \).

6. Average peak hour load factor, is given by

\[ U_6 = Q_{q'} \]  

(18)
7. Average cost per kilometer, including all modes, is given by,

\[ U_7 = \frac{\sum_m \sum_k E^k_{ml} d_{mk} b^k_{ml}}{\sum_m \sum_k E^k_{ml} d_{mk}} \]

where \( b^k_{ml} \) is the operating cost per kilometer for the mode \( m \) on the route \( k \).

8. Average daily road usage, for a kilometer stretch of the link, including all modes, is given by,

\[ U_8 = 2 \times \frac{\sum_m R_m g_m}{\sum_m R_m} \]

where \( g_m \) is the road usage coefficient for mode \( m \).

9. Total yearly accidents, for all modes as given by,

\[ U_9 = \sum_m \sum_k E^k_{ml} h_m \]

where \( h_m \) is the annual number of accidents for one effective vehicle on road of mode \( m \).

10. Total employment for all modes as given by,

\[ U_{10} = \sum_m \sum_k E^k_{ml} e_m \]

where \( e_m \) is the employment per effective vehicle on road of mode \( m \).
11. Average energy per capacity km, including all modes, as given by,

\[ U_{11} = \sum_{m} \sum_{k} \frac{E_{ml,dm,k} \cdot am \cdot v_{ml}}{m \cdot k} \]  \hspace{1cm} (23)

where \( v_{ml} \) is the average energy required per capacity-km for mode \( m \).

12. Average daily passengers per vehicle in the stretch of mode \( m \) is given by,

\[ U_{12} = \frac{V}{m} \] \hspace{1cm} (24)

7.6. Evaluation Process

It may be noted that the composition model calls for simultaneous evaluation of a number of outcomes or objectives, instead of a single objective. All the attributes discussed in the previous section, are important enough to be considered in the model and hence cannot be easily eliminated.

Also from the ideas emerged out from chapters 2 and 3 it may be highlighted that a transport decision cannot be the sole decision of the transport planner, but various interest groups, who are associated with the plan, need to be invited for contributing their views on the problem. In our case we may consider at least the following parties, who have important roles in decision making,
1. The government
2. Passengers
3. Private operators
4. Government operators

Thus our problem becomes one of the "Multi-person multi-criteria" type according to the classical literature of optimization theory.

Multi-person multi-criteria is a relatively new concept. Although a number of researchers contributed significantly to the subject, yet it is still a challenging field and researches are continuing in order to find easy and suitable solutions for such problems. Arrow (1) has pointed out that it is not possible to have a group utility function, as there are certain lacuna in the consistency property in the system. But Kirkwood (1976) (2) later showed that there exists an additive group utility function which satisfies only the pareto optimality.

Recently Delphi Techniques have been found to be quite effective to converge to a consensus decision. The idea of Keeney and Raiffa (3) is fascinating, where they suggest that among the decision makers, there is always a Supra-Decision maker whose judgement ultimately wins. The method of Contini and Zionts (4) tells about an universally accepted arbitrator whenever there is any disagreement. In fact in this process, the problem gets converted to restricted bargaining problem.
Banerjee (5) devised a discrete version of the problem, where ultimate decision is influenced by "indifference bands" of the decision makers.

Any of the established techniques may be applied to our model. But care should be taken such that the technique can be easily understood by all the groups of decision makers.


5. Banerjee B.P., Multiperson Multi Criteria Decision Making, the Institute of Mathematical Study and Operational Research, Technical University of Denmark, 1980.


In this particular study, a Spread-sheet (6?7) based analysis is interesting, as it has interactive facilities and graphic capacities. The interest groups may sit together in front of the computer and try out various compositions and ultimately converge to a particular solution which may be accepted by all the groups.

In stead of direct interactions, because of various limitations of time and other constraints, the following modified procedure was followed for evaluation purposes.

1. The micro-model for College Street stretch was chosen for an example.

2. Supply domain was decided through existing data and interviews. Specific suggestions were considered. For example, traffic police do not want any increase of tram frequency on the stretch.

3. Aggregate demand was measured throughout week days and on proper investigation of the data, the following time intervals and corresponding average hourly aggregate demands were established:

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Hourly Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>South bound</td>
</tr>
<tr>
<td>8-00 - 9.30 A.M.</td>
<td>1200</td>
</tr>
<tr>
<td>9-30 - 12 Noon</td>
<td>5100</td>
</tr>
<tr>
<td>12 - 4 P.M.</td>
<td>2820</td>
</tr>
<tr>
<td>4 - 7 P.M.</td>
<td>2010</td>
</tr>
<tr>
<td>7 - 8-30 P.M.</td>
<td>1070</td>
</tr>
</tbody>
</table>
4. Alternatives were input to a "Spread-sheet" model, by considering 5-10% increase of private, CSTC and Minibuses, while 10-20% reduction in trams. The solutions as formulated in the previous section, were instantaneously evaluated and displayed on the Computer Screen.

5. The representatives of the interest groups were interviewed in order to suggest some desired values or ranges of the attributes of our consideration. This needed proper explanation of the situation to them and also examples of attribute values were presented and interpretations were explained to them.

6. Using the "expert opinion values" of each attribute, the deviation factors of the alternatives were evaluated and finally all the deviations were summed up in order to get the net deviation of each alternative. Mathematically, let

\[ T_j^p \] be the outcome of the jth attribute for alternative p, and \[ T_j^* \] be the expert opinion value of the jth attribute,

Then \[ D_j^p = \frac{T_j^p}{T_j^*} \times 100 \] is the deviation factor, expressed in percentage.

Thus \[ |D_j^p - 100| \] is the net deviation for the factor j. Hence \[ N^p = \sum_j |D_j^p - 100| \] is the net deviation for the alternative p.
7.7. Results of the Experiment

All in all 10 alternatives were generated as displayed in the table 7.1. It may be pointed out that the alternative 1 represents the existing system. In alternative 2, private buses were increased by 10%, in alternative 3, private buses were increased by 5%, in alternative 4, CSTC buses were increased by around 10%. In the alternative 5, minibuses were increased by around 15%. In alternatives 6 and 7 trams were reduced by more than 10% and 20% respectively. In the alternative 8, the private buses were reduced by 10% along with the state of trams in alternative 7.

In the alternative 9, further to 8, CSTC buses were increased by 10%. Finally in the alternative 10, further to 9, the minibuses were increased by around 15%.

The outcome vectors of the above alternatives are displayed in the table 7.2. It may be observed that the attributes 2, 5, 7, 9, 10 have considerable variations among the alternatives, while the other attributes do not have much variations. Average peak-hour load factor has 19% variations, yearly accidents have 16% variations, average cost per kilometers and kilometerage per day have variations 11% each. Thus effects of these attributes may be considered to be dominant in the experiment.

It is interesting to note that average revenue per vehicle (for the particular zone of College Street, of our experiment) varies widely for minibuses and trams, for various
alternatives. In case of minibus, the variation is 18%.
Because the trams have been reduced by more than 20% in some alternatives, the variation in revenue is around 17%.

The interest groups, mainly the government, the transport operators and the users were asked about their feelings on the attributes. The values they set for the attributes are displayed in the table 7.3 and the corresponding net deviations of alternatives are shown in the table 7.4.

It may be observed from the table 7.4 that the alternative 6 has the smallest net variation and hence is a good compromise. This means that if the tram fleet on the corridor is reduced by around 10%, better results may be achieved. It is also important to note that alternatives 7, 8 and 10 are marginally better than the existing composition.
<table>
<thead>
<tr>
<th>Alternative</th>
<th>1</th>
<th>2</th>
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### The Simulated Outcomes of Different Alternatives

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<td>10.88</td>
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<td>11.07</td>
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<td>69.06</td>
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<td>78.3</td>
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<td>68.04</td>
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### Table 7.3

**Range of Attributes and Decision Makers Views**

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<tr>
<th>Attribute</th>
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<th>Decision Makers</th>
<th>Desired value</th>
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<td>1. Capacity utilisation</td>
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<td>Users</td>
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<td>4. Average peak hours speed</td>
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<td>10.86</td>
<td>Users</td>
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<td>5. Average peak hour load factor</td>
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<td>Operators</td>
<td>73.00</td>
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<tr>
<td>d. Tram</td>
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<td>Operators</td>
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<tr>
<td>e. Special Bus</td>
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### Table 7.4

**Net Deviations of Alternatives**

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