PERFORMANCE EVALUATION OF BUS DEPOTS USING AHP

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ABSTRACT

This paper presents the development of a bus depot evaluation system, for a public bus transportation system in Chennai city of India. It is to regulate existing bus depot operations. At present there is no such system for bus depot evaluation for Chennai city. The bus depot evaluation system has been developed considering various performance indicators and attributes keeping in mind the rules and regulations of the metropolitan transport corporation of Chennai. Analytic Hierarchy Process (AHP) model is built, which integrates quantitative and qualitative attributes of the depots. The model has been applied to evaluate 4 bus depots of Chennai metropolitan transport corporation. Considering all the performance indicators, the developed system prioritized all four depots from best to worst. The sensitivity analysis has been carried out to find the importance of the criteria and sub criteria for the alternatives using Expert Choice 11.5

Keywords: Analytic Hierarchy Process, Metropolitan bus depots, depots evaluation, sensitivity analysis, performance indicator.
INTRODUCTION

Urban Cities play a vital role in promoting economic growth and prosperity. The development of cities largely depends upon their physical, social, and institutional infrastructure. In this context, the importance of urban transportation is paramount. There must be a general recognition that without public transport, cities would be even less viable. There is a need to encourage public transport instead of personal vehicles. This requires both an increase in quantity and quality of public transport and effective use of demand as well as supply-side management measures. The tasks of urban public transportation are to meet the increasing demands of all kinds of passengers and to earn corresponding social and economic profits in a prescribed period of time by providing high quality of service based on limited public traffic vehicles.

Among all the public transportation systems, buses are the most popular and most commonly used ones because of their inherent flexibility, adaptability to changing employment and residential patterns, and low capital costs. Therefore, many researchers focused on improving bus transportation systems by reducing the cost of operations, minimizing waiting times, improving the quality of service, etc. The buses for different routes in the metropolitan city are operated from the bus depots.

One of the important aspects that affect the performance of the bus transit system is the performance of the bus depot. Since bus transit system serves several depots, the performance of the depots has a direct bearing on the bus transit performance. Hence it is proposed to develop a model to evaluate the performance of bus depots. The performance of depots depends on several criteria. Some of these criteria are quantitative (operational income, fuel consumption, etc.) in nature and some are qualitative (road condition, traffic congestion, etc.). So, it is proposed to use a Multi Criteria Decision Making (MCDM) tool to evaluate the routes. The MCDM tool which can deal with both qualitative and quantitative factors is Analytical Hierarchy Process (AHP).

LITERATURE ON DEOT EVALUATION

Performance evaluation of bus depot is one of the important aspects of transit planning system. It provides valuable information based on which important operating decisions can be taken. Yeh et al (2000), using mulicriteria analysis, obtained an overall
performance index for each of the alternatives considered to assess bus system performance in Taiwan. Wang and Dong (2002) studied a set of criteria for transit project evaluation. Joneth and Darinka (2004) calculated the efficiency of British bus transport industry by using DEA. Borvornvongpitak and Tanaboriboon (2005) developed a Computerized Bangkok Bus Transit Analytical System, (BBTAS), to enhance the performance evaluation of the existing bus system in Bangkok. Huang et al. (2007) have developed a model to evaluate existing bus routes and relocate transit resources in Beijing city using AHP.

Fielding et al (1978, 1985a, b) offer an impressive number of indicators that can be used to evaluate transit performance. In this work, they argued that the goals of both the Federal and state governments could be achieved by the provision of efficient and effective services. Three categories of indicators (efficiency, effectiveness and overall indicators) have been proposed.

METHODOLOGY

Conventional decision-making processes often consider quantitative criteria whereas multi-criteria approach involves both qualitative and quantitative criteria. There exist processes like utility function approach to handle qualitative criteria and various optimization techniques for quantitative techniques. AHP is one such effective tool, which can handle both types of criteria. It was developed by Thomas L. Saaty in the year 1980 (Saaty et al. 1980, 1986). AHP has been used for the prioritization exercise in this study. The scale developed by Thomas L. Saaty is used to make pairwise comparisons, which are subsequently synthesized to get the final priorities of the alternatives (Saaty 1990). Geometric mean method (GMM) has been widely applied method in AHP for aggregation of individual preferences (Aczel and Saaty, 1983; Korhonen and Wallenius 1990).

DESIGN OF AHP MODEL FOR BUS DEPOT EVALUATION

A comprehensive bus depot evaluation system according to the conditions of the Indian bus transit system has been developed. The model consists of four main criteria and nineteen sub-criteria. Figure 1 shows the proposed hierarchy structure of bus depot evaluation model. The major criteria selected for evaluation are service measure,
operation measure, financial measure, and administrative measure. These criteria are arrived at based on discussion with the bus operators and passengers and also referring to literature. The evaluation identifies the operating conditions and existing problems so as to provide an objective basis for requisite decision for regulating depots, such as withdrawing a depot, or combining depots or establishing new depots, and improving service and efficiency of depots. The AHP model has the goal of evaluating the depots based on the main criteria and sub-criteria.

A. SERVICE MEASURES LEVEL:

Service Measures level indicates the convenience, Quality & types of services, Quality of employees and fleet & route performance and effectiveness of a bus depot.

B. FINANCIAL MEASURES LEVEL:

The financial measures level denotes the financial performance of the depot in terms of collection, fuel cost etc.

C. OPERATIONAL MEASURES LEVEL:

The operational measures level is the degree of effectively utilizing labour resources and materials in the depot operation.
D. ADMINISTRATIVE MEASURES LEVEL:

The Administrative measures level denotes the performance of administration with respect to time management, inspections, infrastructure development and training for employees.

DEFINITIONS FOR SUBCRITERIAS:

A. SERVICE MEASURE LEVEL

1. Quality of personal

This sub-criterion measures the skills and working ability of the employees and assess whether the service persons (Driver/Conductor) are user-friendly to the passengers. This qualitative data consider as performance of depot with respect to service quality of the employees.

2. Total number of Fleets Available

This sub-criterion indicates “How many numbers of buses (including spare vehicles) available in the bus depot”.

3. Types of Services

Types of services denotes “how many numbers of services available in the depot like Volvo a/c, Deluxe, Express, M-Series, Ordinary services etc.”

4. Quality of Service

Quality of service indicates “how well the service offered to the customers with respect to the depot” this qualitative data consider as performance of depot with respect to service quality.

5. Number of Routes handled

This sub-criterion indicates how many numbers of routes handling by the depot to the various destinations.

B. FINANCIAL MEASURES LEVEL:

1. Collection/bus/day

It is the ratio between the total collections of money (in rupees) per bus to total statistical period. Here statistical period is one month.
2. Earning per km. (EPKM.)

This financial level sub-criteria defines by ratio between the total collection of money to gross kilometers running by all the buses in the depot.

3. Fuel Cost per km

This financial level sub-criterion defines by the ratio between the total fuel costs of all the buses in the depot to gross operated kilometers by all the buses in depot.

C. OPERATIONAL MEASURES LEVEL:

1. Gross Km's

Gross kilometres of the depot is the total operated kilometres in the statistical period by all the buses in depot. This sub-criterion indicates total running distance of the depot per statistical period.

2. Gross Kmpl

Gross kilometres per litre defines by ratio between the total operated kilometres (i.e.) Gross kilometres to the total fuel consumption (in litres) by the depot.

3. Avg. Km / Bus / Day

This sub-criterion indicates the average kilometers operating per bus per day during a statistical period. Its define by ratio between Average kilometers/day to total fleets available in the depot.

4. Fleet Utilization

This sub-criterion defines ratio between total operated fleets to total fleets available in the depot (including spare vehicles). Its indicates “how fleets are effectively used by depots”

5. Tyre Life in Km

This sub-criterion indicates life span of the tyre or the effective usage time of each tyre per operated kilometres of the buses in the depot.

6. Percentage of trip loss

It is the ratio between the actual total operated trips to total scheduled trips. Due to unfortunate incidents (i.e.) accidents, technical fault, environmental condition, of the buses in the depots may not cover the scheduled trip
D. ADMINISTRATIVE MEASURES LEVEL:

1. Time Management

This qualitative sub-criterion measures how effectively manage the time in the depots in terms of schedules, trips, shifts, services from the customer point of view.

2. Training & Motivation for Employees

This sub-criterion defines the degree of improving the technical skills and stimulating the interest of employees by means of technical and financial factors. It enables to provide more authority for the employee to self-manage and make decisions.

3. Depot Infrastructure

This sub-criterion measures the quality of depot infrastructure such as sufficient parking facility for fleets, garage facility, fuel storage, staff amenities, availability of electricity, water and other resources.

4. Regular Inspection

This qualitative sub-criterion denotes the “scheduled regular examine of the depot” with respect to the routes, fleets and administration. This is ensures the performance of the depots.

5. Vehicle Condition

This sub-criterion denotes the condition of buses in terms of physical condition of the vehicles and interior condition of the vehicles such as seat condition, windows with respect to depots.

APPLICATION OF MODEL TO A REAL CASE

The required quantitative and qualitative data have been collected from the four depots of Metropolitan Transport Corporation (MTC), Chennai, India. MTC cover an area of around 1177 square kilometres with 500 routes controlled by 25 depots. Around 37 lakh passengers travel per day in MTC buses. The data are collected from the passengers travelling in the route and the officials working in the depot of MTC.

PROCEDURE OF PRIORITIZATION

Once the hierarchy structure of the Bus Depot Evaluation has been constructed, the prioritization procedure begins to determine the relative importance of the elements at each level. A questionnaire was designed using Satty’s scale and data are collected from
50 persons, including both passengers and management personnel. Out of 50 responses, 40 samples have shown consistency. For the quantitative factors, data are collected from the respective depot and are converted by normalization and inserted into the pair wise comparison matrix (PCM). After doing all pair wise comparisons at level 1, the same procedure is extended to all factors with respect to the second level.

SYNTHESIS OF PRIORITIES

The local priorities that express the relative impact of the set of elements on an element in the level immediately below can be generated by using the set of pair wise comparison matrices (PCM). We first compute a set of Eigen vectors for each matrix and then normalize to unify the result so as to obtain the vectors of priorities. For the problem under consideration, a sample PCM table for a single response with respect to goal is given in Table 1.

Table 1 Pair wise Comparison Judgment Matrix and Weights with Respect to the Goal

<table>
<thead>
<tr>
<th>Service Measures</th>
<th>Financial Measures</th>
<th>Operational Measures</th>
<th>Administrative Measures</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Measures</td>
<td>1</td>
<td>1/3</td>
<td>1/2</td>
<td>0.15</td>
</tr>
<tr>
<td>Financial Measures</td>
<td>1</td>
<td>1/2</td>
<td>1/2</td>
<td>0.15</td>
</tr>
<tr>
<td>Operational Measures</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0.36</td>
</tr>
<tr>
<td>Administrative Measures</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0.33</td>
</tr>
</tbody>
</table>

C.R = 0.04

Table 1 shows the pair wise comparison between the main criteria. The last column of the table shows the weightage of main criteria. From the table, it is evident that operational measures are the most important one among the other main criteria, whereas service and financial measures are equally important among the other main criteria. Similar calculations are carried out for all the responses. The pair wise comparison is made between alternatives based on the other criteria and alternatives.
The geometric mean is used (Aczel and Saaty 1983) to aggregate the pair wise comparisons from all samples. The local weights of the factors and attributes, and the consistency ratio of each matrix, are analyzed by the procedure as previously mentioned. According to Satty (1986), the global weights are synthesized from the second level down by multiplying the local weights by the corresponding criterion in the level above and adding them for each element in a level according to the criteria it affects. Table 2 shows the consistency test results and Table 3 summarizes the local weights and global weights. All CR values in Table 2 are lower than 0.1, and therefore all the judgments are consistent.

<table>
<thead>
<tr>
<th>Level</th>
<th>Consistency Ratio</th>
<th>Consistency Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal</td>
<td>0.04</td>
<td>Accepted</td>
</tr>
<tr>
<td><strong>Criteria</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service Level</td>
<td>0.07</td>
<td>Accepted</td>
</tr>
<tr>
<td>Financial measure level</td>
<td>0.04</td>
<td>Accepted</td>
</tr>
<tr>
<td>Operational measure level</td>
<td>0.07</td>
<td>Accepted</td>
</tr>
<tr>
<td>Administrative measure level</td>
<td>0.07</td>
<td>Accepted</td>
</tr>
<tr>
<td>Main criteria</td>
<td>Sub-criteria</td>
<td>Local weights</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------</td>
<td>---------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D1  D2  D3  D4</td>
</tr>
<tr>
<td></td>
<td>No. of Routes Handled</td>
<td>0.45 0.29 0.24 0.26</td>
</tr>
<tr>
<td></td>
<td>Total No. of Fleets available</td>
<td>0.24 0.31 0.35 0.20</td>
</tr>
<tr>
<td></td>
<td>Types of service</td>
<td>0.13 0.33 0.21 0.15</td>
</tr>
<tr>
<td></td>
<td>Quality of Service</td>
<td>0.10 0.11 0.18 0.20</td>
</tr>
<tr>
<td></td>
<td>Qulality of Personal</td>
<td>0.06 0.35 0.30 0.05</td>
</tr>
<tr>
<td></td>
<td>Collection / Bus / Day</td>
<td>0.68 0.24 0.36 0.16</td>
</tr>
<tr>
<td></td>
<td>Earning per Km (EPKm)</td>
<td>0.23 0.13 0.26 0.06</td>
</tr>
<tr>
<td></td>
<td>Fuel Cost / Km</td>
<td>0.08 0.34 0.16 0.43</td>
</tr>
<tr>
<td></td>
<td>Gross Km's</td>
<td>0.39 0.42 0.16 0.27</td>
</tr>
<tr>
<td></td>
<td>Gross KmPL</td>
<td>0.22 0.1 0.27 0.33</td>
</tr>
<tr>
<td></td>
<td>Avg. Km. / Bus / Day</td>
<td>0.15 0.60 0.06 0.26</td>
</tr>
<tr>
<td></td>
<td>Fleet Utilization</td>
<td>0.09 0.56 0.26 0.11</td>
</tr>
<tr>
<td></td>
<td>Tyre Life in Km's</td>
<td>0.07 0.03 0.10 0.59</td>
</tr>
<tr>
<td></td>
<td>% of Triploss</td>
<td>0.04 0.04 0.08 0.24</td>
</tr>
<tr>
<td></td>
<td>Time Management</td>
<td>0.45 0.23 0.22 0.34</td>
</tr>
<tr>
<td></td>
<td>Training &amp; Motivation for employees</td>
<td>0.24 0.19 0.38 0.21</td>
</tr>
<tr>
<td></td>
<td>Depot Infrastructure</td>
<td>0.13 0.29 0.43 0.18</td>
</tr>
<tr>
<td></td>
<td>Regular Inspection</td>
<td>0.10 0.27 0.32 0.07</td>
</tr>
<tr>
<td></td>
<td>Vehicle Condition</td>
<td>0.06 0.18 0.27 0.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Rank**
LOCAL WEIGHT OR LOCAL PRIORITY

The local weight for each main criterion is determined. It is the weight of the main criteria relative to the weight of the sub-criteria. The local weights are obtained from the respective pair wise comparisons.

GLOBAL PRIORITY OR GLOBAL WEIGHT

The global weight of each alternative is obtained by multiplying the local weights of major criteria, sub-criteria and alternatives (Table 3). The ranking is done based on overall priority value.

RESULTS

The final ranking of the routes of the selected bus depot of MTC, Chennai, are listed in Table 4. From this, it is observed that Depot 1 has the highest overall priority value of 0.287 and ranked as first. Similarly, all other depots are ranked based on the overall priority. Depot 3 has the least rank. This means that depot 3 has to be studied further in detail to improve its performance.

Table 4 Overall ranking of depots

<table>
<thead>
<tr>
<th>Bus depot</th>
<th>Priority level</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>28.7%</td>
<td>1</td>
</tr>
<tr>
<td>D2</td>
<td>26.5%</td>
<td>2</td>
</tr>
<tr>
<td>D3</td>
<td>21%</td>
<td>4</td>
</tr>
<tr>
<td>D4</td>
<td>23.8%</td>
<td>3</td>
</tr>
</tbody>
</table>

SENSITIVE ANALYSIS

Sensitivity analysis has been performed to see how well the alternatives perform with respect to each of the criteria (objectives) as well as how sensitive the alternatives are to changes in the importance of the objectives. The sensitivity analysis has been carried out using the software, Expert Choice version 11.5.

A performance sensitivity graph shows how well each alternative performs with respect to each of the major objectives (criteria). The importance of the objectives is depicted by vertical bars (Figure 2).

In the sensitivity graphs, the vertical bars represent the criteria and the alternatives are displayed as horizontal lines. The intersection of the line graph with the
vertical line shows the priority of the alternative for the given criterion, as read from the 
right axis labelled Alt%. The priority of each criteria is represented by the height of its 
bar as read from the left axis labelled Obj%. The height of the vertical bar represents 
overall priority of the major criteria.

Figure 2 Performance graph of goal priority

Figure 2 shows the priority of major criteria with respect to goal. This graph 
depicts the actual results from the AHP model. To examine the sensitivity of each criteria 
level, the weight of each criterion has to be changed and the ranks of alternatives are 
recorded.

Figure 3 shows the performance sensitivity of operational measures criteria with 
respect to goal and its effect on alternatives, respectively. It is to be noted that the original 
ranking D1 > D2> D4 > D3 is changed to D1 > D4> D2 > D3 when operation measure is 
changed from 14.8% (actual value) to 24.5% (Table 5). That is, up to a service level of 
24.4%, the actual ranking did not change. Similarly, the sensitivity is examined with 
other major criteria and presented in Table 5. Also change in alternative ranking is 
studied when the actual value of operational measure is changed from 14.8% to 100% 
and presented in Table 5 and is shown graphically (Figure 4).
Figure 3 Sensitivity of operational measures when changed from 14.8 - 24.5

Figure 4 Sensitivity of operational measures when changed from 24.5 – 100%

Table 5 Sensitivity analysis of main criteria

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>ORIGINAL%</th>
<th>CHANGED%</th>
<th>Com%</th>
<th>Original priority</th>
<th>changed</th>
<th>C.C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Measures</td>
<td>36.3%</td>
<td>58.4</td>
<td>62.3</td>
<td>1,2,4,3</td>
<td>2,1,4,3</td>
<td>2,1,3,4</td>
</tr>
<tr>
<td>Financial Measure</td>
<td>32.6%</td>
<td>94.8</td>
<td>100</td>
<td>1,2,4,3</td>
<td>1,4,2,3</td>
<td>1,4,2,3</td>
</tr>
<tr>
<td>Operational Measure</td>
<td>14.8%</td>
<td>24.5%</td>
<td>100</td>
<td>1,2,4,3</td>
<td>1,4,2,3</td>
<td>1,4,2,3</td>
</tr>
<tr>
<td>Administrative</td>
<td>16.3%</td>
<td>42.2%</td>
<td>100</td>
<td>1,2,4,3</td>
<td>2,1,4,3</td>
<td>2,1,4,3</td>
</tr>
</tbody>
</table>

From Table 5 it is seen that operational measure is more sensitive than all other criteria. This is because a difference of 9.7% in operational measure (24.5 -14.8) resulted in the change of ranking of alternatives. The second more sensitive criterion (factor) is service measure.
Sensitivity analysis of all the sub-criteria of service measure has been performed and the results are presented in Table 6

Table 6 Sensitivity Analysis of service measure sub-criteria

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>ORIGINAL %</th>
<th>CHANGED%</th>
<th>Com%</th>
<th>Original priority</th>
<th>changed</th>
<th>C.C</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of route handled</td>
<td>13.7</td>
<td>31.2</td>
<td>66.9</td>
<td>2,1,3,4</td>
<td>1,2,3,4</td>
<td>1,3,4,2</td>
</tr>
<tr>
<td>Total No. Of fleets</td>
<td>10.2</td>
<td>39.9</td>
<td>55.5</td>
<td>2,1,3,4</td>
<td>1,2,3,4</td>
<td>3,1,4,2</td>
</tr>
<tr>
<td>Types of service</td>
<td>22.7</td>
<td>34.2</td>
<td>100</td>
<td>2,1,3,4</td>
<td>2,3,1,4</td>
<td>3,2,1,4</td>
</tr>
<tr>
<td>Quality of service</td>
<td>37.6</td>
<td>75.6</td>
<td>100</td>
<td>2,1,3,4</td>
<td>2,3,1,4</td>
<td>2,4,3,1</td>
</tr>
<tr>
<td>Quality of personnel</td>
<td>15.7</td>
<td>24.2</td>
<td>65.1</td>
<td>2,1,3,4</td>
<td>1,2,3,4</td>
<td>1,2,4,3</td>
</tr>
</tbody>
</table>

From the Table 6 it is observed that quality of personnel (8.5%) and type of service (11.5%) are more sensitive in that order. The service measure can be improved by paying more attention to the quality of personnel and type of service.

CONCLUSION

In this study, a set of bus depot evaluation criteria for a bus transit system consisting of four major criteria and nineteen sub-criteria are identified and an AHP model has been designed. The model has been employed to evaluate some of the bus depots of the Chennai Metropolitan Transport Corporation, Chennai. Solution to the model was obtained by using Expert Choice software. Sensitivity analysis has been carried out to examine how sensitive the alternatives are to changes in the importance of the objectives. From the analysis it is found that the major criteria operational measure has more influence on the performance of the depots. Further, the sub-criteria of the depot, namely quality of person, and type of service play a major role in the performance of the depots. So, by concentrating on these aspects, the management can improve the depot efficiency.

REFERENCES