TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 7550 - 7559

Evaluation and Optimization of Route Network Using AHP

[1]Prof. Sachin S. Pund [2]Dr. D. R. Zanwar
[1]Assistant Professor, Department of Industrial Engineering. Shri Ramdeobaba College of Engineering and Management,Nagpur.
[2]Associate Professor, Department of Industrial Engineering. Shri Ramdeobaba College of Engineering and Management,Nagpur.

Article Info
Volume 82
Page Number: 7550 - 7559
Publication Issue:
January-February 2020

Article History
Article Received*: 18 May 2019*
Revised*: 14 July 2019*
Accepted*: 22 December 2019*
Publication*: 04 February 2020*

Abstract:
This paper discusses the development of a comprehensive bus route evaluation system using various performance indicators according to rules and regulation of Nagpur Municipal Corporation. Analytic Hierarchy Process (AHP) model is built, which integrates quantitative and qualitative attributes of the routes. To demonstrate the real world application of this developed system 4 bus routes from Nagpur city have been taken for study. Considering all mentioned performance indicators, the developed system prioritized all seven routes from best to worst. The sensitivity analysis is carried out to find the importance of the criteria and sub-criteria for the alternatives using Expert Choice 11.5.

Keywords: Analytic Hierarchy Process, bus route

I. Introduction:

Performance evaluation of bus routes is one of the important aspects of transit planning system. It provides valuable information based on which important operating decisions can be taken. There have been some achievements at home and abroad on the transit evaluation. Koski (1992) brought forward detailed evaluation criteria for the bus route planning. Yeh et al (2000), using multicriteria 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. 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. Giannopoulos (1989) put forward the transit evaluation criteria composed of efficiency and benefit. Yedla and Shrestha (2003) examined the importance of various evaluative criteria for the selection of alternative transportation in Delhi, India. From the literature, it is observed that studies related to route evaluation of Indian bus transit system are not reported. In Indian metropolitan cities, the operating circumstances of bus transport are greatly different from that of abroad, such as mixed traffic flows, developing motorization, etc. Moreover, there is no systematic bus route evaluation criteria designed for Indian bus transit system. In this study an attempt has been made to develop an AHP model for evaluating bus routes of a metropolitan city.

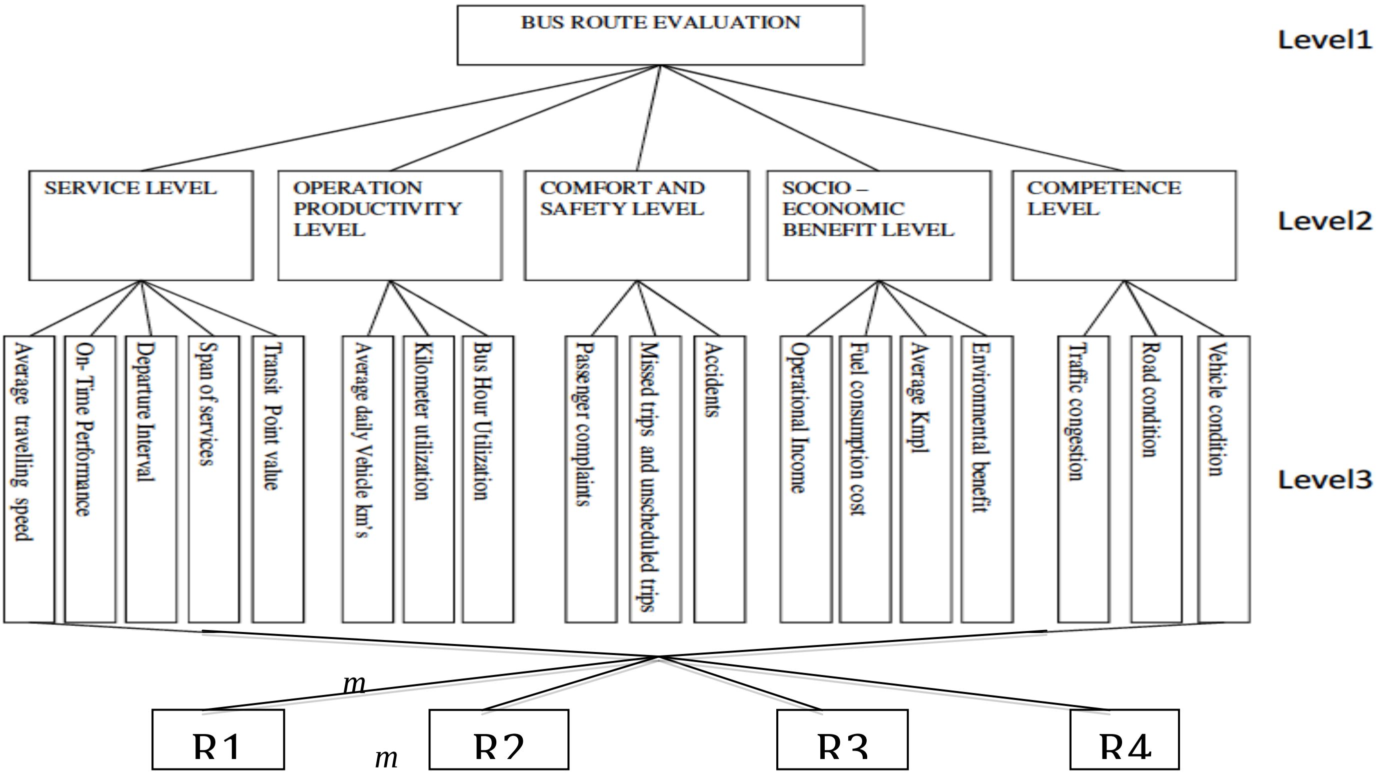
Criteria for Bus Route Evaluation:

A comprehensive bus route evaluation criteria system according to the conditions of the Indian bus transit system has been developed. The

TEST Engineering & Management
January - February 2020
ISSN: 0193 - 4120 Page No. 7550 - 7559

model consists of five main criteria and eighteen sub-criteria. Figure 1 shows the hierarchy structure of bus route evaluation model.

Fig. 1: Hierarchy Structure of bus route evaluation model



3.0 All criteria used in AHP model for bus route evaluation are explained:

(a) Average traveling speed (S):

It is the ratio of length of the bus route to the travelling time from source to destination. It measures the quality of the bus and the condition of the bus route. Factors that affect the traveling speed consist of the road condition, traffic, bus condition, etc.

$$\mathbf{S=\sum_{i=1}^{m}\sum_{j=1}^{n}(L/t_{ij})/\sum_{k=1}^{m}n_k}$$

Where: L = Total length of the bus routes in Km.

i= 1,2,……….. m buses;

j= 1,2,……….. m trips;

t_{ij} = time of ith bus for jth trip

n_k = number of trips made by the Kth bus

$$S=\sum_{i=1}^{m}\sum_{j=1}^{n}(L/t_{ij})/\sum_{k=1}^{m}n_k$$

where L =Total length of the bus routes in km.

i = 1, 2, …m buses;

j = 1, 2… n trips

t_{ij} = time of ith bus for jth trip

n_k = number of trips made by the Kth bus

(b)On-time Performance (OTPR):

It is the ratio of number of on-time departures according to the schedule of a route to total number of departures. The departure time is allowed a deviation of ±2 min from the schedule. Generally, it should not be less than 80%. It measures the reliability of the route. Vehicle dispatch, road condition, management, etc. affect this criterion.

$$OTPR=(\sum_{i=1}^{m}\sum_{j=1}^{n}(p_{ij})/\sum_{k=1}^{m}n_k)$$

Where p is a binary variable; p = 1 means

January - February 2020
ISSN: 0193 - 4120 Page No. 7550 - 7559

departure is on time; p = 0 means is not on time.

(c)Departure Interval (During a Peak Period) (DI):

It is the bus departure interval at the terminus during peak time. This is a measure of convenience and reliability of bus service delivered to satisfy passengers during peak hours. DI = T_d /N Where N = total number of departures, T_d = Time duration of peak period

(d)Span of Service (SOS): It is the time duration in a day during which services operated.

SOS = LSF – ESS Where LSF = Late service finishing time, ESS = Earliest service starting time

(e)Transit Point Value (with Public Transit Hub):

It is the value between a bus route and the nearest public transit hub such as suburban railway station, airport, suburban bus terminus and, local train station. If the route has more number of public transit hubs each public transit hub carries 1 point. This is a measure of passenger convenience for transfer from the particular route from one mode of transport to another mode of transport or from one route to another route.

(f)Average Daily Vehicle-Kilometers (ADVK):

It is the average number of kilometers operating per day per bus during study period. It is also called daily vehicle speed. This criterion measures the degree of operation efficiency.

$$ADVK = [\sum_{k=1}^{m} n_k * L]/m \text{ Km / day}$$

(g)Kilometers Utilization (KU):

It is the ratio of operation passenger kilometers to total operation kilometers or gross kilometers. The gross kilometers include passenger kilometers and dead head-trip.

It is a measure of vehicle operating utilization.

$$KU = [(\sum_{k=1}^{m} n_k * L)/G]*100$$

where

G = gross kilometers

Bus Hour Utilization (BU)

It is the ratio of bus operating hours on the route to total bus hours registered. It measures the efficiency of managing vehicles.

Comfort and safety level:

Comfort and safety level indicates the comfort and safety of passengers while travel in the bus route. This consists of three sub-attributes.

(h)Passenger Complaints: The level of passenger complaints indicates the route performance. All complaints are recorded in a record book which is provided by the transit management.

(i)Missed trips and Unscheduled Extra Trips: Sometimes buses are not operated as per schedule, i.e., some extra trips are operated or some trips withdrawn from the regular schedule. While missed trip causes inconvenience to passengers, unscheduled extra trips add burden to the management.

(j)Accidents: This sub-attribute defines the number of accidents in a particular route during the study period. An accident record book is maintained at each depot. It measures level of safety in the route for commuters.

Socio-Economic Benefits:

These criteria deal with the benefits to society and bus operators. This measure

directly reflects the effectiveness of using the bus transport and how environment friendly with the society. This is divided into four sub-attributes.

(k)Operational Income: It is the income from service charges (fare collected from passengers) on a route in certain study period. This criterion measures the economic benefit of a route.

(l)Fuel Consumption Cost: It is the product of quantity of fuel (liters) actually consumed by the buses on a route and cost of fuel/liter. This criterion is a measure of the consumption quantity of fuel for operating buses and fuel utilization.

FCC = [(l * R)]

Where l = consumption fuel in liters; R = Rupees

Table: 1

FUEL CONSUPTION COST		
ROUTES	VALUE	WEIGHT
R1	28560	0.143
R2	70560	0.354

TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 7550 - 7559

R3	71650	0.359
R4	28800	0.144
	199570	

(m) Average KMPL: This sub-attribute indicates the average operation kilometers per liter of fuel actually consumed by buses in particular route. This is a measure of the fuel efficiency of the route

$$AverageKMPL=[\sum_{i=1}^{m}(G_i/l_i)/m]km/l$$

Where, Gi = Gross kilometers run by ith bus; li = total liters of fuel consumed by ith bus

(n) Environmental Benefit: The emission level differs from bus to bus based on fuel used and type of engine. For example, a bus having BS III engine will carry one point, bus with BS II engine carries two points. A bus with 6.65 HINO type engine carries three points. So the route with minimum points shall have more environmental benefits.

Competence Level: This attribute is a measure of the fitness or adequacy of the bus route for operation of services. This is classified into three sub-attributes as follows.

(o)Traffic Congestion: This sub-criterion indicates the traffic density of the particular route. It measures the convenience of the route in terms of traffic.

(p)Vehicle Condition: This sub-criterion measures the physical condition of the vehicle, i.e., structure of the vehicle, age of the vehicle, seats, and windows, capacity of the vehicle, etc.

(q)Road Condition: This sub-criterion measures the physical condition of the road, i.e. curves, signals, quality of the road, capacity of the road etc. Actual data are available for, Service level, Operation and Productivity level, Comfort and safety level, and Socioeconomic benefit level among the five attributes, and hence that they are treated as quantitative factors. The attribute Competence Level that includes Traffic condition, Vehicle condition and Road conditions is a qualitative factor.

4.0: Application of AHP Model: All relevant data required for determining values of various evaluation criteria was collected. Figure – shows map of Nagpur city. Amongst numerous route utilized by corporation bus service, 4 routes were selected for present study.

Fig.2 City Map showing routes:

Table: 2 ROUTES SELECTED FOR EVALUATION

S/N	NAME OF ROUTES	BUS SCHEDULE (24 HRS)	INTERVAL (MIN)	KM	NO. OF BUSES	TRIPS	SPAN OF SERVICE (HR:MIN:S)	Three trips made on each route and time taken to complete one trip		
								Morning	Noon	Evening

1	BULDI- DEFENCE	5:50 – 11:00	10	16	15	5 EACH	16:40:00	28 MIN	35 MIN	32 MIN
2	BULDI – HINGNA	6:00 - 11:30	10	16	20	7 EACH	17:00:00	39 MIN	44 MIN	40 MIN
3	BULDI – KAMPTEE	6:00 - 11:35	10	18	20	7 EACH	17:00:00	38 MIN	43 MIN	40 MIN
4	PARDI - BULDI	6:10 - 11:10	10	10	10	9 EACH	17:00:00	44 MIN	50 MIN	47 MIN

Table: 3 CALCULATED DATA:

ROUTES	ATS (KM/HR)	OTPR	DEPARTURE INTERVAL (MIN)	SPAN OF SERVICE (SOS)	TRANSIT POINT VALUE	ADVK	KILOMETER UTILIZATION	BUS HOUR UTILIZATION
BULDI – DEFENCE	12.8	0.69	3.84	17hr	1	180 km	86.95%	92%
BULDI – HINGNA	29.86	0.72	3.18	15.30hr	0	160 km	91.4%	98%
BULDI – KAMPTEE	22.56	0.71	3.14	17hr40min	0	224 km	91.4%	94%
PARDI - BULDI	26.85	0.71	3.3	17hr40min	1	252 km	92.3%	94%

Table: 4 WEIGHTAGE CALCULATED FOR QUANTITATIVE DATA

WEIGTHAGE TABLE				
	R1	R2	R3	R4
ATS	0.139	0.324	0.245	0.292
OTPR	0.244	0.254	0.251	0.251
DI	0.285	0.236	0.233	0.245
SOS	0.251	0.229	0.260	0.260
TP	0.500	0.000	0.000	0.500
ADVK	0.221	0.196	0.275	0.309
KU	0.240	0.252	0.252	0.255
BU	0.243	0.259	0.249	0.249
FCC	0.143	0.354	0.359	0.144
AKPL	0.313	0.25	0.219	0.219

Fig.3 CALCULATION OF QUALITATIVE DATA MAIN CRITERION SUMMARY SHEET:

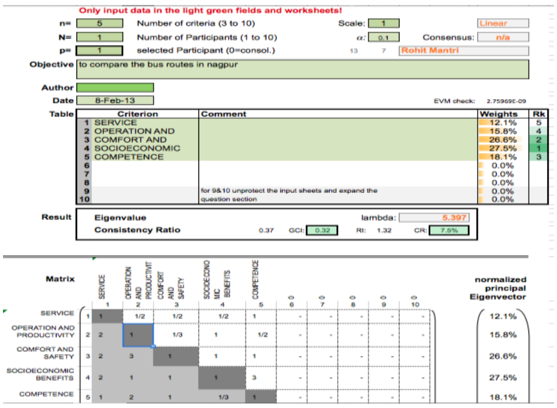
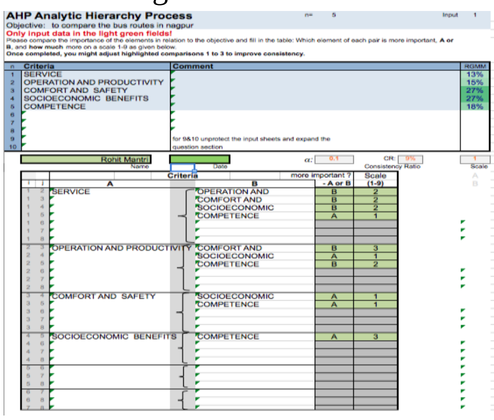


Fig.4 INPUT SHEET:

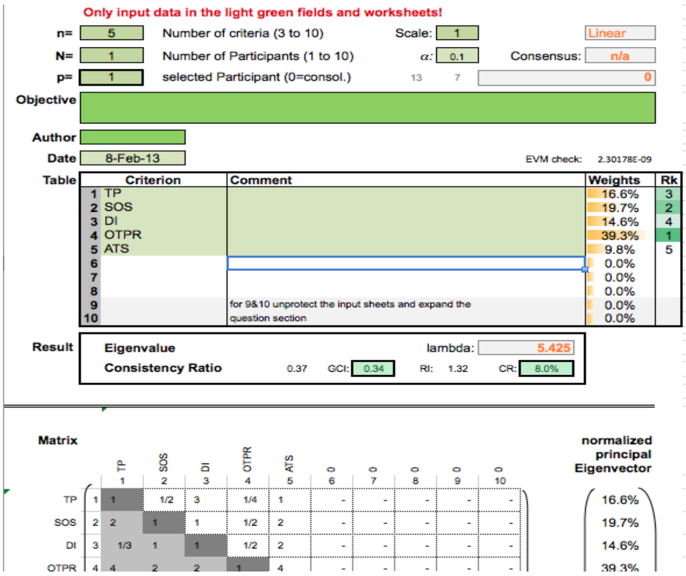


SUB –CRITERION:

TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 7550 - 7559

Fig.5 SERVICE LEVEL SUB CRITERION:SUMMARY SHEET:



Similarly weights were calculated for every qualitative sub – criterion selected.

Now the relative route weights were calculated for every sub – criterion

Fig.6 SUMMARY SHEET FOR TRAFIC CONGESTION SUB-CRITERIA:

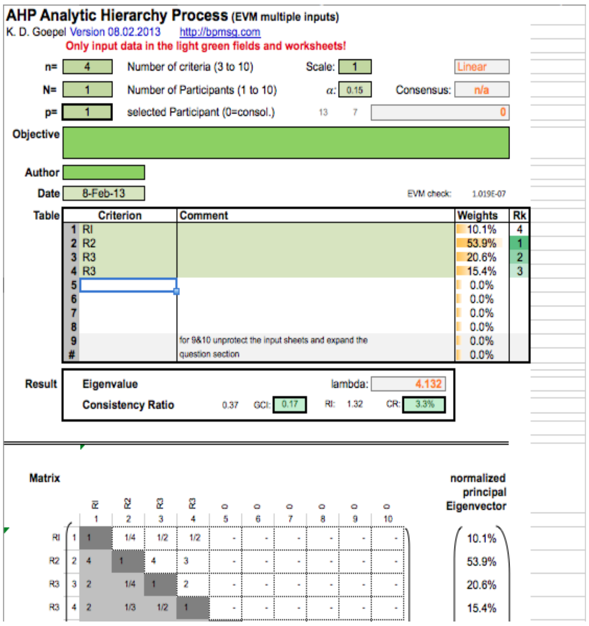


Fig.7 INPUT SHEET:

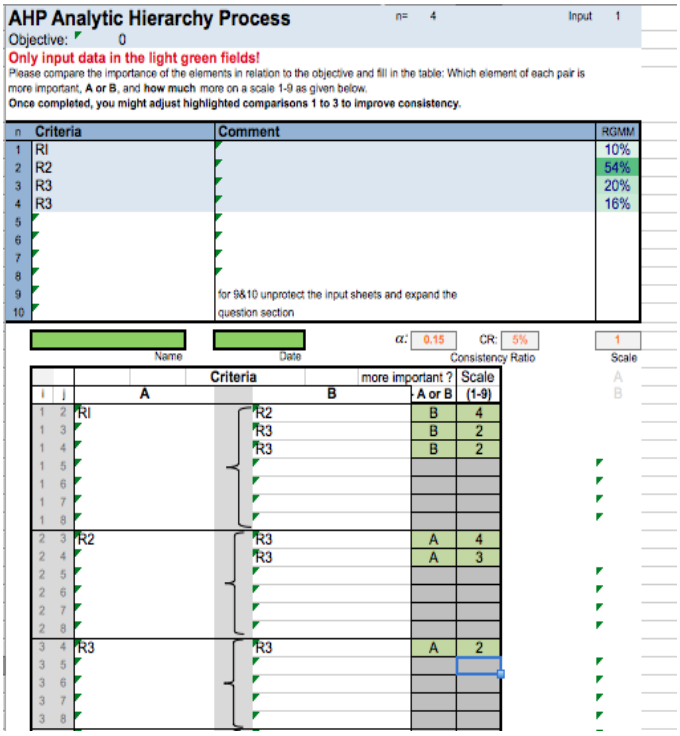


Table:5 CONSISTENCY TEST FOR CRITERIAS:

LEVEL	CONSISTENCY RATIO	CONSISTENCY RATIO
GOAL	0.07	ACCEPTED
CRITERIA		
SERVICE LEVEL	0.08	ACCEPTED
OPERATION PRODUCTIVIY LEVEL	0.02	ACCEPTED
COMFORT AND SAFET LEVL	0.07	ACCEPTED
SOCIO - ECONOMIC BENEFITS	0.09	ACCEPTED
COMPETENCE LEVEL	0.07	ACCEPTED

Local Weight and Global Weight for Each Criteria:

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

January - February 2020
ISSN: 0193 - 4120 Page No. 7550 - 7559

multiplying the local weights of major criteria, sub-criteria and alternatives. The ranking is done based on overall priority value.

RESULTS: The final ranking of the routes of public buses in Nagpur are listed in Table. From this, it is observed that Route 2 has the highest overall priority value of 0.3243 and ranked as first. Similarly, all other routes are ranked based on the overall priority. Route 1 has the least rank. This means that Route 1 has to be studied further in detail to improve its performance.

Table: 6

ROUTES	ROUTE'S NAME	PRIORITY VALUE	RANKING
R1	BULDI – PARDI	0.1731	4
R2	BULDI – DEFENCE	0.3243	1
R3	BILDI – HINGNA	0.2121	3
R4	BULDI - KAMPTEE	0.2908	2

Sensitivity 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.A performance sensitivity graph shows how well each alternative performs with respect to each of the major objectives (criteria). Vertical bars depict the importance of the objectives (FIGURE 1). 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 labeled Alt%. The priority of each criteria is represented by the height of its bar as read from the left axis labeled Obj%. The height of the vertical bar represents overall priority of

The major criteria.

Table: 7

LOCAL WEIGHTS								GLOBAL WEIGHTS			
MAIN CRITERIA		SUB-CRITERIA		ALTERNATIVES				ALTERNATIVES			
NAME	L WEIGHT	NAME	L WEIGHT	R1	R2	R3	R4	R1	R2	R3	R4
SERVICE	0.121	ATS	0.098	0.139	0.324	0.245	0.291	0.0016	0.0038	0.0029	0.00345
		OTPR	0.393	0.243	0.254	0.250	0.250	0.0116	0.0121	0.0119	0.01189
		DI	0.146	0.285	0.236	0.233	0.245	0.005	0.0042	0.0041	0.00433
		SOS	0.197	0.250	0.228	0.260	0.260	0.006	0.0054	0.0062	0.0062
		TPV	0.166	0.500	0.000	0.000	0.500	0.01	0	0	0.01004
OPERATION PRODUCTIVITY	0.158	BU	0.249	0.243	0.259	0.249	0.249	0.0096	0.0102	0.0098	0.0098
		KU	0.594	0.240	0.252	0.252	0.256	0.0225	0.0237	0.0237	0.02403
		ADVK	0.157	0.220	0.196	0.274	0.308	0.0055	0.0049	0.0068	0.00764
COMFORT & SAFETY	0.266	ACCIDENTS	0.21	0.183	0.522	0.113	0.182	0.0102	0.0292	0.0063	0.01017
		M&U TRIPS	0.55	0.136	0.080	0.281	0.503	0.0199	0.0117	0.0411	0.07359
		PC	0.24	0.127	0.477	0.085	0.311	0.0081	0.0305	0.0054	0.01985
SOCIOECONOMIC BENEFITS	0.275	EB	0.501	0.105	0.528	0.105	0.262	0.0145	0.0727	0.0145	0.0361
		AVG. KM/L	0.188	0.219	0.313	0.219	0.250	0.0113	0.0162	0.0113	0.01293
		FUEL COST	0.124	0.144	0.143	0.359	0.354	0.0049	0.0049	0.0122	0.01207
		OPRETION INC.	0.186	0.216	0.144	0.244	0.396	0.011	0.0074	0.0125	0.02026
COMPETENCE	0.181	TC	0.238	0.101	0.539	0.206	0.154	0.0044	0.0232	0.0089	0.00663
		RC	0.136	0.144	0.541	0.203	0.111	0.0035	0.0133	0.005	0.00273
		VC	0.625	0.119	0.451	0.261	0.169	0.0135	0.051	0.0295	0.01912
							SUM	0.1731	0.3243	0.2121	0.29081
							RANK	4	1	3	2

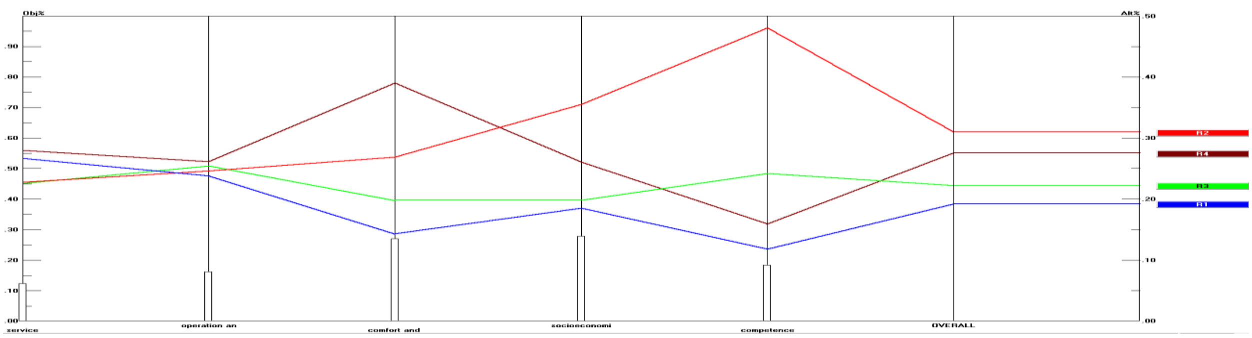
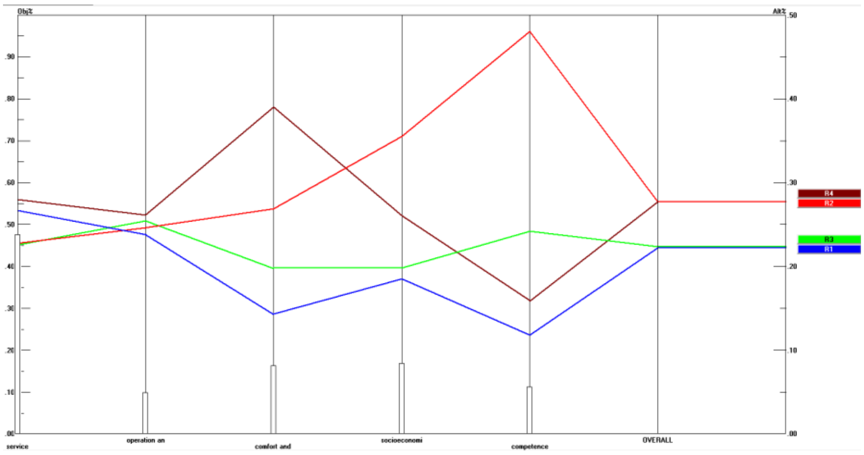


FIGURE 8: Sensitivity graph showing the priority level with respect to goal (Performance graph)

January - February 2020
ISSN: 0193 - 4120 Page No. 7550 - 7559



Figures 9: show the priority of major criteria with respect to goal. (Performance graph)

Figures 2 show 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. Figures 3 show the performance sensitivity of sub-criteria with respect to service level and its effect on alternatives, respectively. It is to be noted that the original ranking (R2 > R4 > R3 > R1) is changed to R4 > R2 > R3 > R1 when service level is changed from 13% (actual value) to 46%. That is, up to a service level of 46%, the actual ranking did not change. Similarly, the sensitivity is examined with other major criteria and presented in Table.

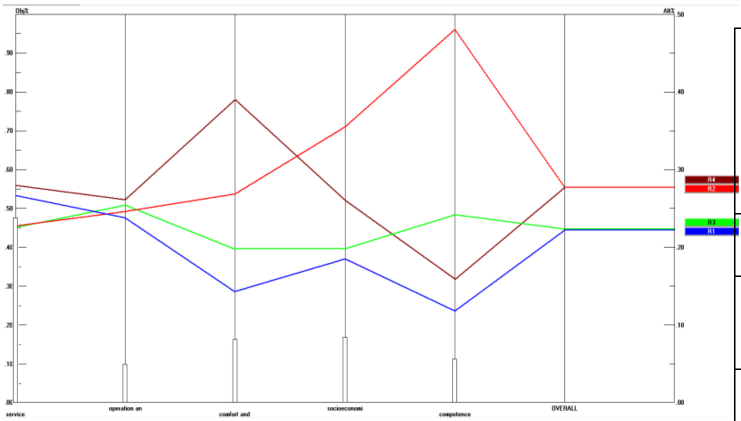


Figure 10: Changes in alternative ranking with respect to service level(performance graph)

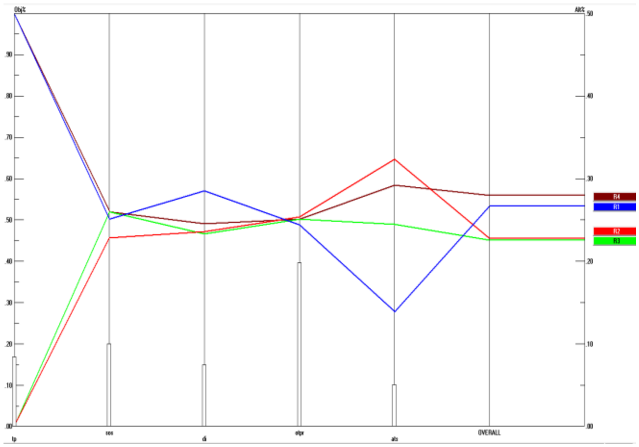


Figure 11: Sensitivity of alternatives with respect to service level (performance graph)

Table: 8 SENSITIVITY ANALYSES OF MAIN CRITERIA:

CRITERIA	ACTUAL PRIORITY VALUE	PRIORITY VALUE AFTER CHANGE	RANKING OF ALTERNATIVE AFTER 1^{ST} CHANGE
SERVICE	0.13	0.46	R4>R2>R3>R1
OPERATIONAL PRODUCTIVITY	0.17	0.76	R4>R2>R3>R1
COMFORT & SAFETY	0.27	0.44	R4>R2>R3>R1
SOCIOECONOMIC BENEFITS	0.28	1	R2>R4>R3>R1
COMPETENCE	0.18	0.52	R2>R3>R4>R1

January - February 2020
ISSN: 0193 - 4120 Page No. 7550 - 7559

Table: 9 SENSITIVITY ANALYSIS OF SERVICE LEVEL SUB – CRITERIA:

CRITERIA	ACTUAL PRIORITY VALUE	PRIORITYVALUE AFTER CHANGE	RANKING OF ALTERNATIVE AFTER 1ST CHANGE
TRANSIT POINT VALUE	0.15	0.95	R4>R1>R2>R3
SPAN OF SERVICE	0.20	0.25	R4>R1>R3>R2
DEPARTURE INTERVAL	0.15	0.32	R1>R4>R2>R3
ON TIME PERFORMANCE	0.40	0.88	R4>R2>R1>R3
AVERAGE TRAVELLING SPEED	0.10	0.26	R4>R2>R1>R3

CONCLUSION

- In this study, a set of bus route evaluation criteria for a bus transit system consisting of five major criteria and eighteen sub-criteria are identified and an AHP model has been designed.
- The model has been employed to evaluate the public bus routes of Nagpur.
- Solution to the model is 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 SERVICE LEVEL and COMFORT & SAFETY LEVEL have more influence on the performance of the routes.
- Further, the sub-criteria of these two, namely SPAN OF SERVICE and MISSED AND UNUSED TRIPS lay a major role in the performance of the routes. So, by concentrating on these aspects, the management can improve the route efficiency. Once the efficiency of routes is improved, the performance efficiency improves.

REFERENCES

1. Aczel, J., and T.L. Saaty, (1983). “Procedures for Synthesizing Ratio Judgments”, Journal of Mathematical Psychology, Vol. 27, pp. 93-102.
2. Fielding, G.J., T.T. Babitsky, and M.E. Brenner, (1985a). “Performance evaluation for bus
3. transit”, Transportation Research 19A (1), 73–82.
4. Fielding, G.J., M.E. Brenner, and K. Faust, (1985b). “Typology for bus transit”, Transportation Research 19A (3), 269–278.
5. Fielding, G.J., Glauthier, and C.A. Lave, (1978). “Performance indicators for transit
6. management”. Transportation, Vol. 7, pp.365–379.
7. Giannopoulos, G.A., (1989). “Bus Planning and Operation in Urban Areas: A Practical Guide”, Gower Publishing Co, pp. 73-96.
8. Korhonen, P., and J. Wallenius (1990). “Using qualitative data in multiple objective linear
9. programming”, European Journal of Operational Research, Elsevier, Vol. 48, No. 1, pp. 81-87.
10. Koski, R.W., (1992). “Bus Transit in Public Transportation”, (Eds: Gray G.E. and Hoel L.A.)”, Prentice Hall, New. Jersey, pp. 162-166.
11. Saaty, T.L., (1986). “Axiomatic foundations of analytic hierarchy process”, Management
12. Science, Vol. 32, No. 7, pp. 841-855.
13. Saaty, T.L., (1990). “How to make a decision: The Analytic Hierarchy Process”, European
14. Journal of Operational Research, Vol. 48, pp. 9-26.
15. Saaty, T.L., P.C. Rogers, and R. Pell, (1980). “Portfolio Selection through Hierarchies”,
16. Journal of Portfolio Management, pp. 16-21.
17. Wang, J., and L. Dong, (2002). “Study on Urban Public Transportation Project Evaluation”,
18. Journal of Transportation Systems Engineering and Information Technology, Vol. 2.
19. Yedla, S., and R.M. Shrestha, (2003). “Multicriteria approach for the selection of alternative
20. options for environmentally sustainable transport system in Delhi”, Transportation Research A, Vol. 37, pp. 717-729.
21. Yeh, C.H., H.Deng, and Y.H. Chang, (2000). “Fuzzy multicriteria analysis for performance
22. Evaluation of bus companies”, European Journal of Operational Research Vol.126, pp. 459–

Authors :
Prof. Sachin S. Pund
a. Assistant Professor, Department of Industrial Engineering. Shri Ramdeobaba College of Engineering

TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 7550 - 7559

and Management, Nagpur University, Nagpur, Maharashtra, 440013, Mobile no : 09423101930

b. Email : pundss@rknec.edu

Dr. D.R. Zanwar

c. Associate Professor, Department of Industrial Engineering. Department of Industrial Engineering, Shri Ramdeobaba College of Engineering and Management, Nagpur University, Nagpur, Maharashtra, 440013 , Mobile no : 09422820004
d. Email : zaunwardr@rknec.edu