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Cost, Time, Risk and Traffic Based City Transportation Shortest Path Problem

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Abstract
Urban transportation systems face challenges of congestion, pollution, and inefficiency due to rapid urbanization and inadequate infrastructure. This paper develops a multi-objective shortest path transportation model for Surat City, incorporating cost, time, risk, and traffic parameters. Using fuzzy programming techniques, the study identifies optimal routes for different transport modes (bus, auto-rickshaw, and bike). Results demonstrate that fuzzy programming provides more efficient solutions compared to traditional goal programming, offering practical insights for sustainable urban transport planning.
Keyword: *Shortest Path, Fuzzy Programming, Transportation, Linear Membership function,*

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I. Introduction

Surat was the famed old port city of Mughal Empire and the major trading center for Arabs, Portugese, British, Dutch and French merchants. After passing through a lean phase, the ascendancy of Surat started in the latter half of twentieth century (SUDA, 1980). In terms of population, Surat is the twelfth largest of the twenty-three metropolitan cities of India. The city is located in the State of Gujarat along the principal rail corridor midway between Bombay and Ahmedabad, the capital cities of the two most industrialized states in India and one of the India's busiest trunk routes (National Highway - 8), provides linkage to Surat City. Surat isthe focal point of a growing industrial belt in South Gujarat and has the advantage of canal irrigated rich agricultural hinterland. In 1989, the Surat area housed 13,282 medium and large scale factories.Central Road Research Institute (CRRI), New Delhi, has conducted a detailed study of traffic and transportation problems in Surat City on behalf of the authorities of Surat Municipal Corporation (S.M.C.) with two objectives, viz.

(i) to work out a traffic management scheme to improve the circulation and the safety of traffic flow; and
(ii) to suggest a suitable transportation system to meet the horizon year travel demand efficiently and economically.

Accordingly, eight basic field studies were carried out during 1988 through census and interview methods. The normally followed procedures were utilized in the field studies. Based on the findings of analyzed field data and the review of secondary data, a traffic management scheme was worked out for the Walled City area of Surat (Sarna et al., 1989) incorporating a low cost plan for optimizing the available infrastructural facilities. An improvement plan of road network and the public bus transport system is being evolved (Reddy et al., 1993) to meet the predicted travel demand in entire Surat area.

The traffic and transport problems of Surat City owe their origin to the lop-sided nature of the prevailing pattern of population settlement in two distinct parts of the City, namely Walled City and outer area. The population the city has grown from about 0.9 millions in 1981 to 1.5 millions in 1991. The current population densities varies from 10,400 per sqkm to 53,000 per sqkm., the highest being in the core area called walled city. In reality the population density in the walled city has marginally declined on account of changing land use from residential to commercial. The expected future population densities are likely to vary between 34,000and 50,000 per sqkm.

Transport Systems

The transport systems of Surat City are mainly road based. The travel needs of the residents are met by a variety of transport modes namely scooters, mopeds, auto-rickshaws, cars, buses, cycles, trucks, mini trucks, hand carts, bullock carts, etc. The inadequacy of mass transport system has propelled the growth of individual private modes of transport and consequent traffic problems like congestion, air and noise pollution. The spurt in the number of Motorized Two Wheelers (M.T.Ws) comprising of motor cycles, scooters and mopeds on the one hand and auto-rickshaws (i.e. three wheeler smaller version of taxis, but without doors) on the other in Surat is staggering. The number of M.T.Ws in 1969 was lower than that of cars and accounted for just 28 percent of the total of 12,500motor vehicles. However, by 1978, M.T.Ws constituted 5 percent of the total of 43,000 motor vehicles and in 1990,77 percent of the total of 260,000.

The road network in Surat City has grown from 372 kms in 197 to 644 kms in 1990, showing an average increase of 18 kms per annum. In the recent past there has marginally been a higher rate of increase in road length per annum. The vast majority of roads in the Walled City area are centuries old and archaic. There was hardly any systematic road widening program except in a few isolated cases. The concept of a hierarchical order of roads istotally missing. Although the space occupied by the existing network of streets, covers one sixth of the area in the Walled City, much ofits utility is frittered away in the form of too many obsolete and narrow streets/ lanes, and unplanned and uncontrolled intersections. In the rest of Surat area, radial roads with broader carriageways are provided. However, the linkages between different parts of Surat City are by n means fully satisfactory.

In addition to the 0.26 million registered motor vehicles an estimated number of 0.30 million bicycles and 0.05 million slow category vehicles like horse carts, bullock carts and manually drawn/ pushing types of hand carts which are fitted with either 2or wheelers also operate in Surat City. The nature of mixed traffic can be imagined from the fact that as many as 12heterogeneous types of vehicles, characterized by differing sizes and speeds with varying degree of maneuver abilities, compete with one another for the limited road space. The average composition of traffic flow on a normal working day, shows that the motorized two wheelers and the bicycles together account for about two-thirds of vehicular traffic in the inner and intermediate parts of Surat City. Poor representation of city buses in these figures, indicates the absolute inadequacy of bus services. The overwhelming proportion of motor vehicles shown under cars and others in fact pertains to auto-rickshaws (3 wheeler taxis).

City transportation problem is used to decide optimal path by optimizing cost, time, traffic, risk etc. It is also called as Shortest path transportation problem.

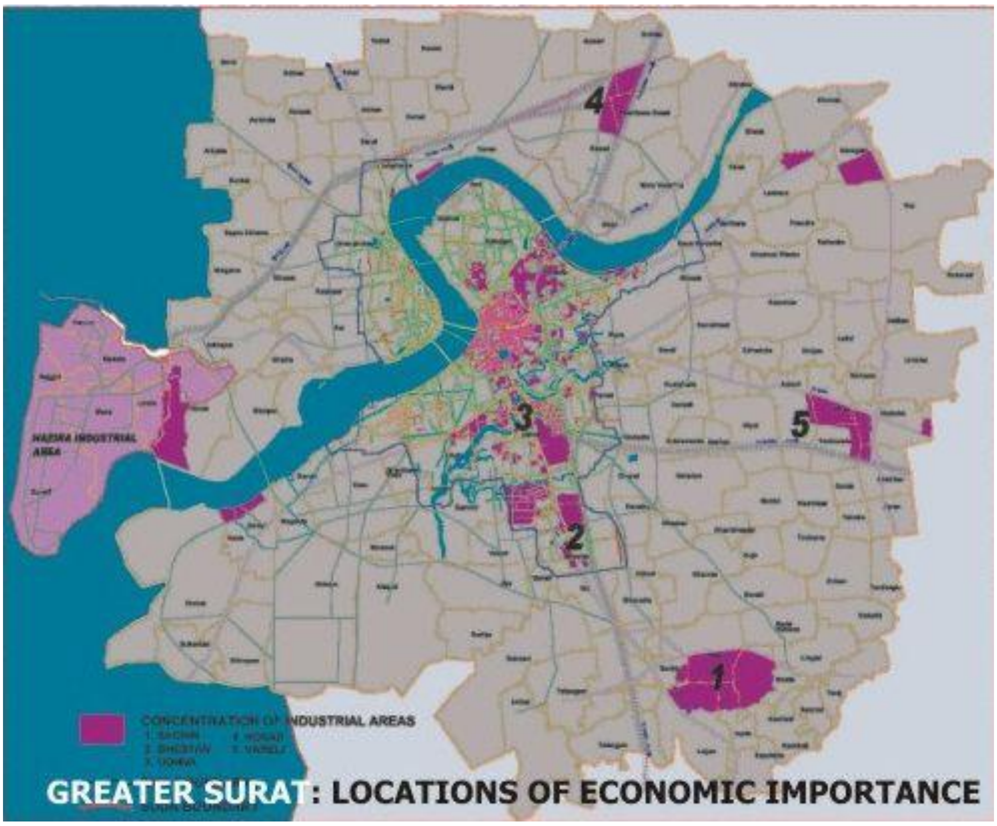

Figure- 1 Surat City and its transportation route

Shortest path transportation problems where the costs have imprecise values are one of the widely studied problems. The shortest path problem was first discussed by Dubois and Prade (1980). However, in their work, even if the shortest distance can be obtained, a matching shortest path cannot be identified (Okada and

Soper, 2000).Other researchers like Tajdin et al., Mahdavi et al., Klein, outlined a model and an algorithm for computing a shortest path in a network having various types of fuzzy arc lengths by a dynamic programming method.

In this paper, multi objective shortest path transportation problem has been developed for Surat city and solved by an approach known as the fuzzy programming technique. The problem is to find the shortest path between two nodes during the transportation. This shortest path corresponds to that path which requires minimum total cost (or time or distance, etc.) of travelling from the source to the sink. For the development of Multi objective shortest path transportation problem data are collected form the Surat city with some hypothetical data.

II. Literature Review

The shortest path problem has been widely studied in transportation research. Early works by Dubois and Prade (1980) introduced imprecise arc lengths, while Okada and Soper (2000) highlighted limitations in identifying matching shortest paths. Subsequent studies by Tajdin et al., Mahdavi et al., and Klein proposed dynamic programming approaches for fuzzy arc networks. Recent advancements emphasize multi-objective optimization in transportation, integrating fuzzy logic to handle uncertainty in parameters such as travel time and traffic congestion (Mehlawat& Gupta, 2016).The multi-objective shortest path problem (MOSP) has seen significant advancements in recent years, particularly in 2025–2026, with researchers focusing on scalability, efficiency, and correctness in handling multiple conflicting objectives such as cost, time, risk, and traffic. Traditional approaches relied on single-valued heuristics and sequential algorithms, which struggled with the complexity of Pareto-optimal solutions. Recent works have introduced GPU-accelerated architectures that allow massively parallel computation of MOSP, achieving speedups of up to 100x compared to sequential methods. These innovations, such as the MPMOS framework, leverage lexicographically ordered label extraction and dynamic memory allocation to efficiently compute exact Pareto frontiers in large-scale networks, including maritime vessel routing and road transport systems. Aniket Todkar et al. have developed several multiobjective optimization-based model for finding out the shortest path [6, 7, 8, 9, 10, 11, 12].

Another line of research has focused on multi-objective multigraphalgorithms, which integrate shallow embeddings and online heuristics to guide search more effectively. This approach improves real-time navigation systems where multiple objectives must be balanced simultaneously. Furthermore, scholars have proposed multi-valued heuristics (MVHs)combined with lazy dimensionality reduction techniques, which preserve correctness while reducing computational overhead. These methods have demonstrated up to 10x speedups in applications such as hazardous material routing and robotic inspection tasks. Overall, the latest literature emphasizes that MOSP is moving from theoretical models toward practical, real-world deployment. The integration of fuzzy logic, heuristic guidance, and parallel computing makes it possible to handle complex urban transportation problems, similar to those faced in cities like Surat, where cost, time, risk, and traffic must be optimized simultaneously. Future directions include expanding MOSP models to handle more than four objectives, integrating IoT-based real-time data, and deploying these algorithms in smart city infrastructure for sustainable urban mobility.

III. Data Collection

For find the solution of cost, time, traffic, risk based transportation problem the concept of network is utilized, we have considering network based transportation system. In this system we have considering a road network of based transportation problem in Surat city. Now, suppose we want to reach at Surat Railway Station from SVNIT Campus then so many paths or routes are there. Among them I am selecting some paths as shown in figure 1.

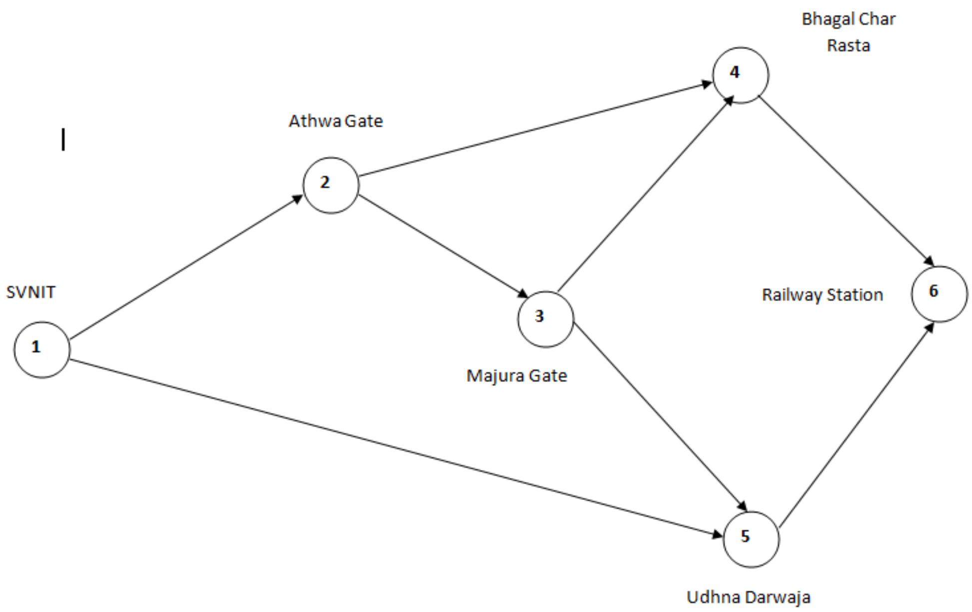

Figure: 1Surat City and its transportation route from SVNIT to Railway station

For network diagram shown in Figure: 1, also consider that three different transportation vehicles are there such as city bus, auto rickshaw and bike. Now, we want to minimize the time, cost, risk and traffic in between two different events or nodes during ride by city bus, by auto rickshaw as well as by bike. For this transportation management problem, we have collected the data (time, cost, risk, traffic) for all activities during ride by above mentioned vehicles. Here, value for risk and traffic parameter is taken in between 1 to 5. Where, 1,2,3,4 and 5 stands for very low, low, moderate, high and very high risk and traffic respectively. From network diagram we can say that eight activities are there. So, for all those eight activities the path and collected data are shown in below.

1.) SVNIT to Athwa Gate

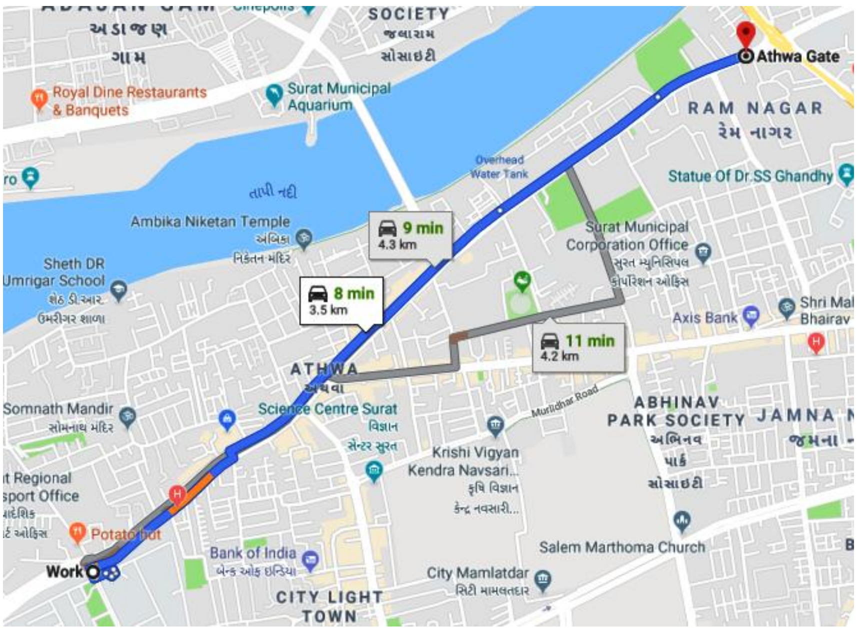

Figure 2 Route of SVNIT to Athwa Gate

Table: 1 Data for SVNIT to Athwa Gate

	By city bus	By auto rickshaw	By bike
Cost (In Rs.)	6	10	5
Time (In minute)	25	10	9
Risk	3	3	2
Traffic	3	3	3

2.) SVNIT to Udhna Darwaja $(1 \to 5)$

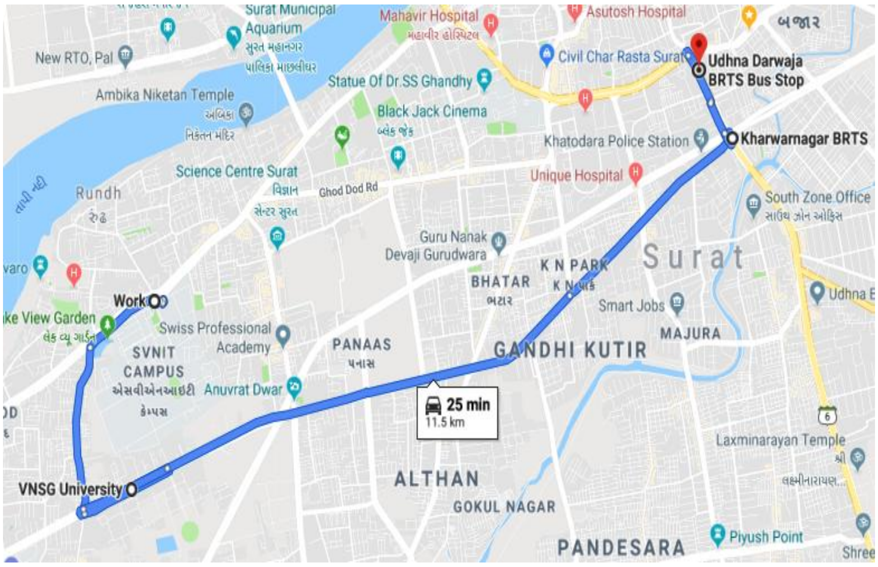

Figure 3 Route of SVNIT to Udhna Darwaja

Table: 2 Data for SVNIT to Udhna Darwaja

	By city bus	By auto rickshaw	By bike
Cost (In Rs.)	8	30	16
Time (In minute)	30	30	25
Risk	5	4	5
Traffic	3	4	4

3.) Athwa Gate to Majura Gate $(2 \to 3)$

Table: 3 Data for Athwa Gate to Majura Gate

	By city bus	By auto rickshaw	By bike
Cost (In Rs.)	4	5	2
Time (In minute)	5	3	2
Risk	1	1	2
Traffic	2	2	3

4.) Athwa Gate to Bhagal Char Rasta $(2 \to 4)$

Table: 4 Data for Athwa Gate to Bhagal Char Rasta

	By city bus	By auto rickshaw	By bike
Cost (In Rs.)	6	15	5
Time (In minute)	10	25	13
Risk	3	5	4
Traffic	5	5	5

5.) Majura Gate to Bhagal Char Rasta $(3 \to 4)$

Table: 5 Data for Majura Gate to Bhagal Char Rasta

	By city bus	By auto rickshaw	By bike
Cost (In Rs.)	6	8	4
Time (In minute)	7	8	9
Risk	4	3	3
Traffic	4	2	2

6.) Majura Gate to Udhna Darwaja $(3 \to 5)$

Table: 7 Data for Majura Gate to Udhna Darwaja

	By city bus	By auto rickshaw	By bike
Cost (In Rs.)	4	5	3
Time (In minute)	4	4	4
Risk	2	1	1
Traffic	1	1	1

7.) Bhagal Char Rasta to Railway Station $(4 \to 6)$

Table: 7 Data for Bhagal Char Rasta to Railway Station

	By city bus	By auto rickshaw	By bike
Cost (In Rs.)	4	5	4
Time (In minute)	12	8	10
Risk	2	4	3
Traffic	4	3	4

8.) Udhna Darwaja to Railway Station $(5 \to 6)$

Table: 8 Data for Udhna Darwaja to Railway Station

	By city bus	By auto rickshaw	By bike
Cost (In Rs.)	4	5	4
Time (In minute)	12	8	10
Risk	2	4	3
Traffic	4	3	4

IV. Mathematical Formulation

The General mathematical construction of Multi objective shortest transportation problem are prepared by means of the following parameters, variables and the indices as per Mehlawat and Gupta (2016).

(1) Indices i and j defines path joining node i and j.

(2) Decision variables

$$x_{ij} = \begin{cases} 1; \ if \ \ path\, ij\, is\, optimal\, path \\ 0; otherwise \end{cases}$$

Formulation of objective functions of Multi objective shortest transportation problem

The total utilized duration, cost, risk and quality level are given as follows [4, 5, 17]:

$$Min\, z_1 = \sum_i \sum_j t_{ij} x_{ij} \,, Min\, z_2 = \sum_i \sum_j c_{ij} x_{ij} \,,$$

$$Min\, z_3 = \sum_i \sum_j r_{ij}\, x_{ij} \,,\ Min\, z_4 = \sum_i \sum_j q_{ij} x_{ij}$$

.

Model constraints of Multi objective shortest transportation problem

The constraints of Multi objective shortest transportation problem are constructed as follows [18].

$$\sum_j x_{1j} = 1 \quad ,$$

$$\sum_j x_{ij} = \sum_k x_{ki} \quad , i = 2, 3, ..., n-1,$$

$$\sum_k^n x_{kn} = 1,$$

$$x_{ij} = 0 \ or \ 1, \forall (i, j) \in A.$$

Multi objective shortest transportation problem Decision problem

The Multi objective shortest transportation problem is formulated as follows [4, 5]:

Model 1

$$(Min\, z_1, Min\, z_2, Min\, z_3, Min\, z_4) = \begin{pmatrix} \sum_i \sum_j t_{ij} x_{ij}\, , \sum_i \sum_j c_{ij} x_{ij}\, , \\ \sum_i \sum_j r_{ij}\, x_{ij}\, , \sum_i \sum_j q_{ij} x_{ij} \end{pmatrix}$$

Subject to the constraints:

$$\sum_j x_{1j} = 1 \quad ,$$

$$\sum_j x_{ij} = \sum_k x_{ki} \quad , i = 2, 3, ..., n-1,$$

$$\sum_k^n x_{kn} = 1,$$

$$x_{ij} = 0 \ or \ 1, \forall (i, j) \in A.$$

By using the table 1. and figure 1 the mathematical form of Multi objective shortest transportation problem (City Bus) is formulated as follows:

Model: 6.2

$$Z_1 = 6X_{12} + 8X_{15} + 4X_{23} + 6X_{24} + 6X_{34} + 4X_{35} + 4X_{46} + 6X_{56};$$
$$Z_2 = 25X_{12} + 30X_{15} + 5X_{23} + 10X_{24} + 7X_{34} + 4X_{35} + 12X_{46} + 12X_{56};$$
$$Z_3 = 3X_{12} + 5X_{15} + 1X_{23} + 3X_{24} + 4X_{34} + 2X_{35} + 2X_{46} + 3X_{56};$$
$$Z_4 = 3X_{12} + 3X_{15} + 2X_{23} + 5X_{24} + 4X_{34} + 1X_{35} + 4X_{46} + 4X_{56};$$

Subject to the constraints:

$$X_{11} + X_{15} = 1;\ X_{12} = X_{23} + X_{24};\ X_{15} + X_{35} = X_{56};$$
$$X_{23} = X_{34} + X_{35};\ X_{24} + X_{34} = X_{46};\ X_{46} + X_{56} = 1;$$

Where X_{ij} is grater than or equal to zero.
To solve multi objective shortest path transportation problem using fuzzy programming approach

V. Fuzzy Programming Solution Approach

To obtain the solution of Model 6.1 by fuzzy programming procedure, first this model is solved for single objective function and for every objective function detect the PIS and NIS of the model. Now, PIS and NIS describe a membership function $\mu(Z_k)$for the k^{th}objective function. To obtain an effective solution of this multi objective Shortest path transportation problem, linear membership functions are utilized. By applying these membership function, the model 6.1 is converted into the following model 3.

Model 3

Max λ ,

Subject to the constraints:

$$\lambda \le \mu_{z_k} \;; 0 \le \lambda \le 1$$

$$X_{11} + X_{15} = 1;\ X_{12} = X_{23} + X_{24};\ X_{15} + X_{35} = X_{56};$$
$$X_{23} = X_{34} + X_{35};\ X_{24} + X_{34} = X_{46};\ X_{46} + X_{56} = 1;$$

When we apply fuzzy linear membership function,

$$\mu_{z^{\varepsilon}_{k}}(x)=\begin{cases}1, & \text{if } z^{\varepsilon}_{k}\le z^{\varepsilon PIS}_{k},\\ \dfrac{z^{\varepsilon NIS}_{k}-z^{\varepsilon}_{k}}{z^{\varepsilon NIS}_{k}-z^{\varepsilon PIS}_{k}}, & \text{if } z^{\varepsilon PIS}_{k}<z^{\varepsilon}_{k}<z^{\varepsilon NIS}_{k},\\ 0, & \text{if } z^{\varepsilon}_{k}\ge z^{\varepsilon NIS}_{k},\end{cases}$$

then model 4 is constructed as follows:

Model 4

$$\max \lambda\,,$$

Subject to the constraints:

$$\lambda\le\frac{z^{\varepsilon NIS}_{k}-z^{\varepsilon}_{k}}{z^{\varepsilon NIS}_{k}-z^{\varepsilon PIS}_{k}}$$

$$X_{11}+X_{15}=1;\ X_{12}=X_{23}+X_{24};\ X_{15}+X_{35}=X_{56};$$

$$X_{23}=X_{34}+X_{35};\ X_{24}+X_{34}=X_{46};\ X_{46}+X_{56}=1;$$

VI. Fuzzy programming technique-based solution approach to solve multi objective shortest path transportation problem

Input: *Parameters:* $(Z_1, Z_2, ..., Z_m, n)$

Output: S*olution of multi objective Shortest path transportation problem*

Solve multi objective Shortest path transportation problem (Z_k, X *)*

begin

read: *problem*

while *problem = multi objective Shortest path transportation problem do*

for *k=1 to m do*

enter matrix Z_k

end

-| *determine the positive ideal solution and negative ideal solution for each objective.*

for *k=1 to m do*

$$z_k^{\text{PIS}}=\min\left(z_i\right), i=1,2,3,4$$

Subject to constraints

end

for *k=1 to m do*

$$z_k^{\text{NIS}}=\max\left(z_i\right),\ i=1,2,3,4$$

Subject to constraints equation

end

-| *Define linear or exponential membership function for each objective.*

for *k=1 to m do*

$$\mu_{z^{\varepsilon}_{k}}(x)=\begin{cases}1, & \text{if } z_{k}\le z_{k}^{PIS},\\ \dfrac{z_{k}^{NIS}-z_{k}}{z_{k}^{NIS}-z_{k}^{PIS}}, & \text{if } z_{k}^{PIS}<z_{k}<z_{k}^{NIS},\\ 0, & \text{if } z_{k}\ge z_{k}^{NIS},\end{cases}$$

end

-| *find single objective optimization model under given constraints from MOP model.*

for*k=1 to m do*

$$Maximize=\lambda,$$

Subject to

Constraints Subject to constraints and

$$\lambda\ge 0;$$

end
|- *find the solution SOP using LINGO software*

VII. Results and Discussion

By solving developed model of multi objective shortest path transportation problem using Lingo 18.0 the obtained result can be summarized as follows:

Table: 9 Results by goal programming approach

Goal programming approach (a)					
	Z_1 (In Rs.)	Z_2 (In minute)	Z_3	Z_4	Critical path
Mode 1 (City bus)	20	49	10	13	$X_{12} \to X_{23} \to X_{34} \to X_{46}$
Model 2 (Auto rickshaw)	28	25	7	7	$X_{12} \to X_{23} \to X_{35} \to X_{56}$
Model 3 (Bike)	23	35	9	6	$X_{15} \to X_{56}$

Table: 10 Results by fuzzy programming approach with linear membership function

Fuzzy programming approach with linear membership function (b_1)						
	h	Z_1 (In Rs.)	Z_2 (In minute)	Z_3	Z_4	Critical path
Mode 1 (City bus)	1	14	42	8	7	$X_{15} \to X_{56}$
Model 2 (Auto rickshaw)	0.5	28	25	7	9	$X_{12} \to X_{23} \to X_{35} \to X_{56}$
Model 3 (Bike)	0.5	17	25	9	9	$X_{12} \to X_{23} \to X_{35} \to X_{56}$

The result show that the developed models of multi objective shortest path transportation problem and their solution provide direct shortest path by considering optimality of all the four objectives cost, time, risk and quality to the travelers of Surat city so they can choose the right path as per their requirement. If this type of model based infrastructure is created for whole Surat city, then people can easily find their optimal route in the city and we can short out several other transportation issues in the Surat city. If we involved technology based infrastructure with such kind of model, then it will be highly benefited to the city transportation problems and their solutions.

VIII. Conclusion

In this paper we have developed particular model of multi objective shortest path transportation problem. Paper also discussed the general model of the problem and then with collected data a particular model is developed for SVNIT Surat to Surat Railway station by data collection from real world and at the end the solutions of that models are achieved.

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