Optimum Route Selection for Vehicle Navigation

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Abstract—The objective of Optimum Route Selection for Vehicle Navigation System (ORSVNS) article is to develop a system, which provides information about real time alternate routes to the drivers and also helps in selecting the optimal route among all the alternate routes from an origin to destination. Two types of query systems, special and general, are designed for drivers. Here, the criterion for route selection is introduced using primary and secondary road attributes. The presented methodology helps the drivers in better decision making to choose optimal route using fuzzy logic. For experimental results ORSVNS is tested over 220 km portion of Haryana state in India.

Keywords—Vehicle Navigation; Route Selection; Fuzzy; Optimum; Navigation System

I. INTRODUCTION

Today, enhancement in advance technologies (communication, sensors, microelectronics and information technology) is technically possible to provide the real time [1] [16] information of traffic conditions to drivers. A Dynamic Route Guidance (DRG) system provides the actual route advice to drivers in real time traffic condition to reduce the traffic delays. This system is implemented in Indian road context, which are categorized in the following parts- Express Way, National Highways, State Highways, Urban Roads and Rural Roads. National Highways and Express ways are the most preferred by the most of the DRG system routes to reach the destination. As there is no Express Way in Haryana (experimental study), it is not included in the presented work. The traffic volume is increasing every year. The production of automobiles in India is in millions of [2] units as shown in Fig. 1, which is the main cause of traffic congestion. The other causes are poor road condition, poor traffic management and heterogeneous mode of transport (Heavy goods vehicle, Trunk, Bus, Mini Bus, Cab and motorcycle etc.). There are three modes of route selection- short, economical and easy to travel. The route with the shortest distance is recommended in short mode. In case of economy mode, the most economical path in terms of fuel, toll plaza and vehicle maintenance cost is recommended. In easy mode, a route is selected which is suitable for easy driving. Firstly, short, mode is most commonly used mode in all DRG systems.

An alternate route provides [3] additional capacity to service primary route traffic. Alternate routes start from one point on primary route and ends at another point as shown in Fig. 2. Some events like the traffic clogging, emergency, natural disasters, traffic incidents, snowstorm, fog, flood, road blockage, forgotten route by drivers are responsible for alternate routes.
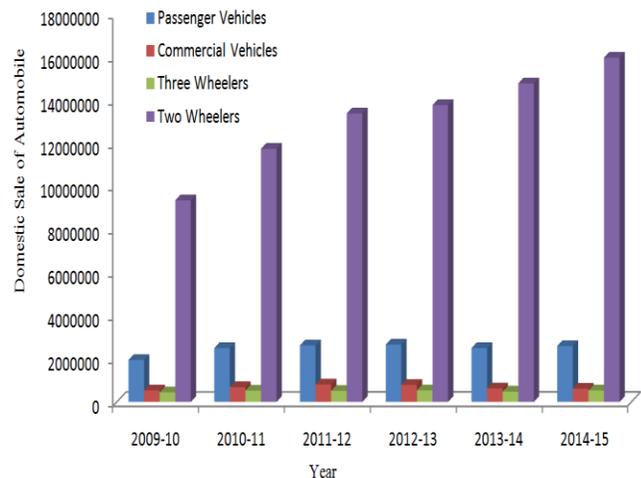

Fig. 1. Domestic Sales of Automobile in India [Source: SLAM]

Fig. 2 shows a road network, which represents three alternate routes with beginning and terminal point on the primary route. In case of blockage of selected route there is need of route diversion and reassignment, which is represented in Fig. 3. Planned events like major roadway construction and maintenance, and unplanned events like traffic incidents, emergency roadwork, adverse weather and emergency are the causes for alternate route plan. The congestion impacts of these events on road capacity are blocked travel lane(s) or road segment, reduce traffic speed and capacity.

A large number of route guidance, alternate route selection, optimum route selection and route diversion systems (Peter Bonsall *et al.* (1992), Kim *et al.* (2003), Mohamed Abdel-Aty *et al.* (2004), Shou-Ren HU *et al.* (2005), Hey Ran Kim *et al.* (2005), Alexander Aved *et al.* (2007), S.S. Keshkamat (2008), Constantinos Antonioua *et al.* (2011), Anastasia Spiliopoulou *et al.* (2013), Xingang Li *et al.* (2014)) have been developed to select the optimum route but a limited technical literature for selecting optimal route to the best of our knowledge is presented here. Peter Bonsall designed a route guidance [4] and information system on route choice for urban networks. Advanced Traveler Information Systems (ATIS) provided [5] alternate routes to driver using generalized estimating equations and binomial probit link function. Time taken to travel on diverted route is less as compared to on normal route thus it increases the probability of diversion. Real-Time Route Diversion Management System (RTRDS) was implemented to [6] create optimal route diversions using available real-time and historical traffic information.
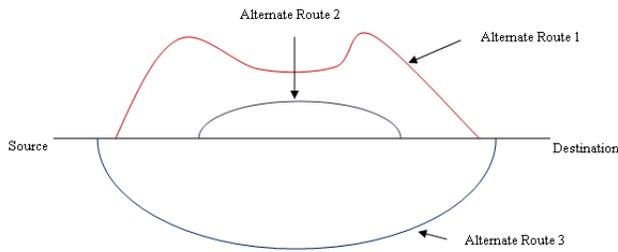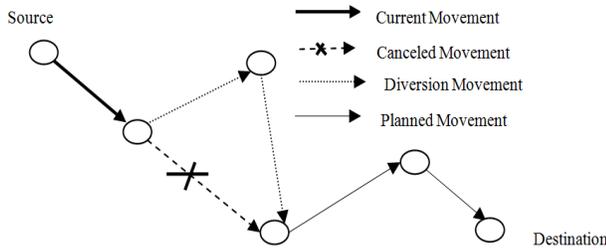
Fig. 2.   Road Network

Fig. 3.   Route Diversion and Reassignment

A flexible and cost-effective systematic framework based [7] on traffic assignment models was designed to analyze the value of traffic information in route diversion control scheme. With the use of online traffic management system, other dynamic route diversion model [8] is developed to capture travelers' route and their switching behavior in real time Adaptive Kalman Filtering technique is also used to present freeway O-D pattern prediction algorithm. The framework presented by Constantinos Antonioua *et al.* has discussed the impact of predictive guidance in reducing average travel time and travel time variability during incidents. The predictive Variable Message Signs (VMS) [9] shifts a significant number of vehicles from routes taking higher travel time to routes taking lower travel time, showing more consequently reduction in delays and efficient utilization of the network capacity. The contribution of onsite information [10] is to estimate the influence of information on drivers' route diversion decision and network performance accurately. To avoid the [11] recurrent motorway congestion, two route guidance policies have been developed, which is triggered by a saturated off-ramp, but is not efficient to resolve the spread out and motorway congestion problem. To resolve this, a second case based [12] on user-optimum considerations was implemented. Xingang Li *et al.* designed the diversion drivers' [13] from expressway to analyze the behavior under different conditions of network and traffic, to find the key factors influencing diversion behavior. Multi criteria methods for high [14] speed rail route selection presented by Mohd Rapik Saat *et al.* for Malaysia. These methods provide a set of tools to analyze and compare the different alternatives for a rail transport route. It is found from the above review of literature that there is a need of existing as well as implementation of new systems, which will help the system users to select more precise optimal route

among all alternate routes on the basis of vehicle type. A fuzzy logic based decision making system is designed to achieve our goal which displays optimal route using experienced based fuzzy score of primary and secondary road attributes.

The rest of the paper is organized as follows. The section I describes introduction and the related work for optimal route selection for vehicle navigation system. The section II presents case study from origin (MM University, Mullana) to destination (Karnal) of Haryana state, India. The road characteristic and discussion on primary and secondary road characteristics is provided in section III. The optimal route selection criterion is discussed in section IV. Section V presents the results and discussion of implemented work. Finally section 6 shows the conclusion and future work of this paper.

II. CASE STUDY: ANALYSIS OF ROUTES FROM MM UNIVERSITY TO KARNAL

From an origin (MM University, Mullana) to destination (Karnal) route is taken with three alternate routes to present the specific problem in this case study. Table I presents route description of one original and three possible alternate routes of Haryana, India. The distance pair between the cities is shown in Table II which is used in analysis of routes from origin to destination. As described in Table II, the distances between two same cities remain zero. Entries below zero shows distance between city pairs in kilometers, miles and nautical miles but entries above zero are blank due to repetition of city pair. Traffic congestion may be more during starting and ending session of the companies and educational institutes. Thus the volume of automobile traffic is higher than the usual at that duration of time. As the driver already knows all feasible routes for a trip, there is a need of selecting optimal route and during the time of journey, before each road junction, the driver has the options to evaluate alternate routes. The driver has to take decision to choose alternate route on the basis of road attribute values. The evaluation of route is measured by number of factors. For instance, if the driver wants to reach his/her destination as soon as possible, the dominant factor would be travel time of all feasible routes from origin to destination.

In case of Route1 blockage or traffic congestion on Route1, alternate routes will be considered, but the problem in choosing more precise optimal route among all alternate routes according to vehicles type arises here. For example Route4 will not be well suitable for heavy vehicles in term of several road attributes like "bridge clearance", "bridge load", "unnecessary detours" and "congested road". The following research gaps are analyzed in this case study.

- No criteria for selecting route according to transportation mode

- No query system designed for general and special query

- No provision for selecting more precise optimal route

The solution of these research gaps and the criteria for optimum route selection are explained in the further sections.

TABLE I. ROUTE DESCRIPTION OF MM UNIVERSITY TO KARNAL

	Original/ Alternate	Stop List	Via	Route Type
Route1	Original	[MM University, Barara, Sahabad, Pipli, Nilokheri, Trarori, Karnal]	Barara	[Urban+ National Highway]
Route2	Alternate	[MM University, Mullana, Kalpi, Saha, Sahabad, Pipli, Nilokheri, Trarori, Karnal]	Saha	[Urban+ National Highway]
Route3	Alternate	[MM University, Dosdka, Chapper, Bhamboli, Yamuna Nagar, Diamla, Radaur, Ladwa, Indri, Rambha Karnal]	Yamuna Nagar	[Urban Only]
Route4	Alternate	[MM University, Barara, Babain, Ladwa, Indri, Rambha Karnal]	Babain	[Urban + Rural]

TABLE II. DISTANCE BETWEEN CITY PAIRS OF HARYANA STATE, INDIA

	Yamuna Nagar	Amabala Cantt	Kurukshetra	Karnal	Panipat	Hisar	Rohatak	Jind
(a) In Kilometers								
Yamuna Nagar	0							
Ambala Cantt	58	0						
Kurukshetra	45	46	0					
Karnal	66	81	37	0				
Panipat	99	120	71	36	0			
Hisar	206	190	162	156	142	0		
Rohatak	180	226	177	116	77	90	0	
Jind	149	151	103	84	68	76	59	0
(b) In Miles								
Yamuna Nagar	0							
Ambala Cantt	58	0						
Kurukshetra	28	28	0					
Karnal	41	50	23	0				
Panipat	62	74	44	22	0			
Hisar	128	118	101	97	88	0		
Rohatak	111	140	110	72	47	56	0	
Jind	92	94	64	52	42	47	36	0
(c) In Nautical Miles								
Yamuna Nagar	0							
Ambala Cantt	58	0						
Kurukshetra	24	25	0					
Karnal	36	43	20	0				
Panipat	53	64	38	19	0			
Hisar	111	102	87	84	76	0		
Rohatak	97	122	95	62	41	48	0	
Jind	80	81	56	45	37	41	31	0

III. ROAD CHARACTERSTICS AND DISCUSSION

A road characteristic is the road attributes which is used by system users to select the route. These characteristics of road are divided into two parts: primary characteristics and secondary characteristics. Influence of the primary characteristics in route selection is more than the secondary characteristics. The presented work uses both characteristics in route selection to achieve reliable results. The primary characteristics include travel distance, travel time, congestion, degree of difficulty, economy, facilities, user friendly and driver stress level. These eight characteristics are widely used in route selection while other are secondary characteristics. They may include- number of turns, traffic signals, road condition, unnecessary detours, traffic incidents, weather, catastrophe, bridge clearance, lane width, bridge load, speed limit etc. Table III shows the importance of road attributes for transportation mode. Most of the attributes are very important for one kind of transport mode while less important for others as explained in table given below.

First two PA like travel time and travel distance are the most important attributes from all other attributes in navigational route selection system. Experience based fuzzy scores are assigned to each road attribute. The fuzzy score 1 is assigned to denote the shortest travel time on a route among the set of feasible routes and a score of 0 is used to denote the longest travel time on a route. Travel distance attribute is similar to the travel time attribute. The fuzzy score 1 of this attribute denotes the shortest travel distance among the set of feasible routes and fuzzy score 0 denotes the longer travel distance. Several causes of road congestion are accidents, road construction, traffic light etc. More congestion on road is denoted by high fuzzy score and low score represents the less congestion on road. Degree of difficulty includes narrowness of road, traffic signals, number of turns, road construction etc. which is difficult for the drive.

A fuzzy score 1 indicates ideal road situation, means easy to drive and score 0 indicates difficult to drive. For example National Highways 1, State Highways 0.8, Urban Road 0.6,

Rural Road 0.3. Economy includes toll plaza, vehicle maintenance cost, fuel consumption etc. A fuzzy score 1 denotes best economy (no toll, low maintenance cost, low fuel consumption) and 0 denotes the worst economy (maximum toll, high maintenance cost, high fuel consumption). Facilities include the available facilities (filling station, automobile station, restaurant, tea shop, ATM machines etc.) on a road. A fuzzy score 1 denotes that more facilities are available on a route and 0 denotes that there is no facility on route. A score 1 denotes that route is more user friendly and low stress level of the driver and 0 score represents that the route is less user friendly and high stress level of the driver.

TABLE III.   IMPORTANCE WISE CLASSIFICATION OF ROAD ATTRIBUTES FOR TRANSPORTATION MODE

	Train	Truck	Bus	Car	Motor Cycle
Primary Attributes (PA)					
Travel Distance	VM	VM	VM	VM	VM
Travel Time	VM	VM	VM	VM	VM
Congestion	I	VM	VM	I	LI
Degree of Difficulty	LI	VM	VM	I	LI
Economy	LI	VM	VM	VM	LI
Facilities	LI	I	VM	VM	VM
User Friendly	NA	NA	NA	NA	NA
Driver Stress Level	LI	VM	VM	I	I
Secondary Attributes (SA)					
Road Condition	NR	VM	VM	VM	LI
Unnecessary Detours	LI	VM	VM	I	LI
Traffic Incidents	NR	VM	VM	VM	LI
Weather	VM	VM	VM	VM	I
Catastrophe	VM	VM	VM	VM	LI
Bridge Clearance	VM	VM	VM	I	LI
Lane Width	NR	VM	VM	I	LI
Bridge Load	VM	VM	VM	I	LI
Speed Limit	VM	VM	VM	VM	VM

Legend: VM- Very Important   I – Important

LI- Less Important   NR- Not Related   NA- Not Analysis

TABLE IV.   PRIMARY AND SECONDARY ATTRIBUTES VALUES

	Route1	Route2	Route3	Route4
Primary Attributes (PA)				
Travel Distance (km)	80	90	85	75
Travel Time (min)	90	110	140	160
Congestion	No	High	Low	No
Degree of Difficulty	No	Minor	Major	Minor
Economy	Very Low	High	Very High	Low
Facilities	More	Few	No	No
User Friendly	More	Less	Less	Medium
Driver Stress Level	Low	Medium	High	Very High
Secondary Attributes (SA)				
Road Condition	Best	Good	Average	Worst
Unnecessary Detours	Few	Medium	More	Few
Traffic Incidents	Medium	More	More	Few
Bad Weather	More Suitable	Suitable	Not Suitable	Not Suitable
Catastrophe	Low	Medium	High	Medium
Bridge Clearance (ft.)	≥ 15	≥ 15	≥ 10	≥ 9
Lane Width (ft.)	≥ 14	≥ 11	≥ 9	≥ 9
Bridge Load (pound)	9000	5000	5000	3000
Speed Limit (kmph)	100	80	60	50

The acceptable values for some other road attributes (bridge clearance, lane width, bridge load and speed limit) are ≥ 15 ft., ≥10 ft., 9000 pounds and ≥ 40 kmph respectively.

The routes which satisfy these conditions will be assigned high score, otherwise low score will be given to them.

IV. OPTIMAL ROUTE SELECTION CRITERIA

As discussed in previous section, a driver can select a route based on primary and secondary road attributes. Two types of the query systems (General and Special) are designed here. In general query system the results are returned on the basis of primary road attributes whereas in special query, the results are returned on the basis of both the road attributes.

The experience based weight is assigned to each road attributes as shown in Table V. These weights are assigned on the basis of road attribute values as given in Table IV. The fuzzy logic is used to select the optimum route for designed system as shown in Fig. 4. In this section a decision making route selection methodology for drivers is presented to select the optimum route for vehicle navigation system using fuzzy logic which is shown in Fig. 4. At first setting of the number of road attributes (primary and secondary) is done then the values of each attributes which are normalized between 0 and 1 are noted, after that classification of road attributes is made for transportation mode. Set the fuzzy rules to each road attribute and assign the experience based fuzzy score to each road attribute.

Rank is assigned to each feasible route on the basis of attribute score. The two input membership function f(x) and g(x) are represented in Fig. 5. Here f(x) is used to show "LOW", "SHORT", "MINIMUM", "FEW" and "MINOR" and g(x) shows "HIGH", "LONG", "MAXIMUM", "MORE", "MAJOR". Five trapezoidal membership functions- "VERY BAD", "BAD", "FAIR", "GOOD" and "VERY GOOD" as shown in Fig. 6. An example of primary and secondary attributes based fuzzy rules is as follows:
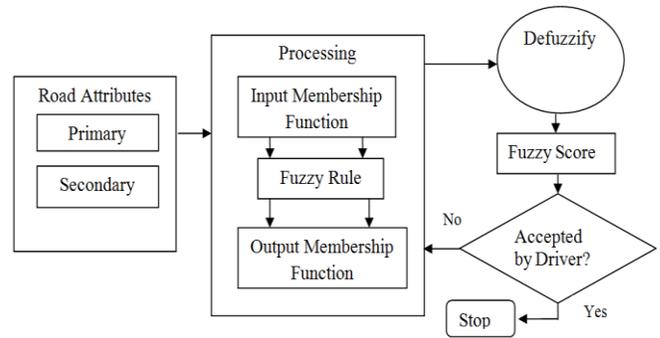

Fig. 4. Optimum route selection methodology

Primary Attribute based Fuzzy Rules as Follow:

Rule 1:

IF	Travel distance is SHORT on Route1 AND Travel distance is LONG on Route2
THEN	Choose Route1 AND Route2 should not be taken

TABLE V. FUZZY SCORE OF ROAD ATTRIBUTES

	Route1	Route2	Route3	Route4
Primary Attributes (PA)				
Travel Distance			0.6	
Travel Time	0.8	0.5	0.6	0.9
Congestion	1.0	0.9	0.8	0.4
Degree of Difficulty	1.0	0.1	0.1	0.5
Economy	1.0	0.9	0.4	0.7
Facilities	0.9	0.2	0.0	0.7
User Friendly	1.0	0.4	0.2	0.0
Driver Stress Level	1.0	0.2	0.7	0.5
	1.0	0.8		0.2
PA Average Score			0.4	
	0.9	0.5		0.4
Secondary Attributes (SA)				
Road Condition	1.0	0.8	0.5	0.1
Unnecessary Detours	0.9	0.5	0.2	0.9
				0.8
Traffic Incidents	0.5	0.2	0.2	0.0
Bad Weather	0.9	0.6	0.0	0.6
Catastrophe	0.8	0.6	0.4	0.5
Bridge Clearance	1.0	1.0	0.7	0.4
Lane Width	1.0	0.8	0.4	0.3
Bridge Load	1.0	0.6	0.6	0.4
Speed Limit	0.9	0.8	0.6	
				0.4
SA Average Score	0.8	0.6	0.4	
				0.4
Total Average Score (PA + SA)	0.8	0.5	0.4	

Rule 2:

IF	Travel time is LARGE on Route1 AND Travel time is SHORT on Route2
THEN	Choose Route2 AND Route1 should not be taken

Rule 3:

IF	Distance is LONG and Congestion is LOW on Route1 AND Distance is SHORT and Congestion is HIGH on Route2
THEN	Choose Route1 AND Route2 should not be taken

Secondary Attribute based Fuzzy Rules as Follow:

Rule 1:

IF	Unnecessary Detours is FEW on Route1 AND Unnecessary Detours is MORE on Route2
THEN	Choose Route1 AND Route2 should not be taken

Rule 2:

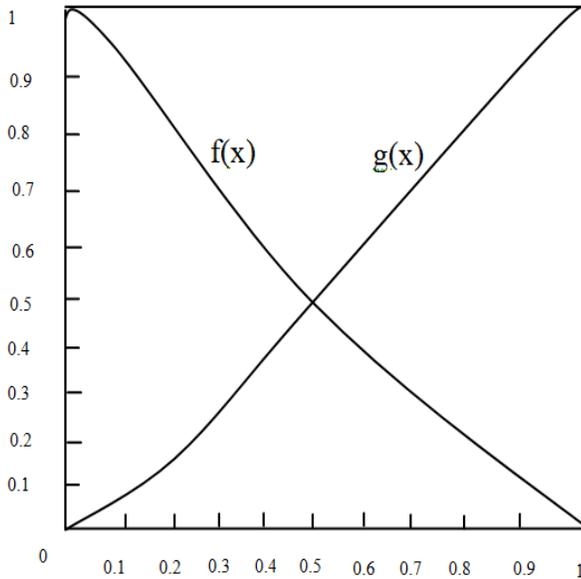| IF	Catastrophe is HIGH on Route1 AND Catastrophe is LOW on Route2
THEN	Choose Route2 AND Route1 should not be taken

Fig. 5. Input membership functions f(x) and g(x) here f(x) for ("LOW", "SHORT", "MINIMUM", "FEW", "MINOR") and g(x) for ("HIGH", "LONG", "MAXIMUM", "MORE", "MAJOR")
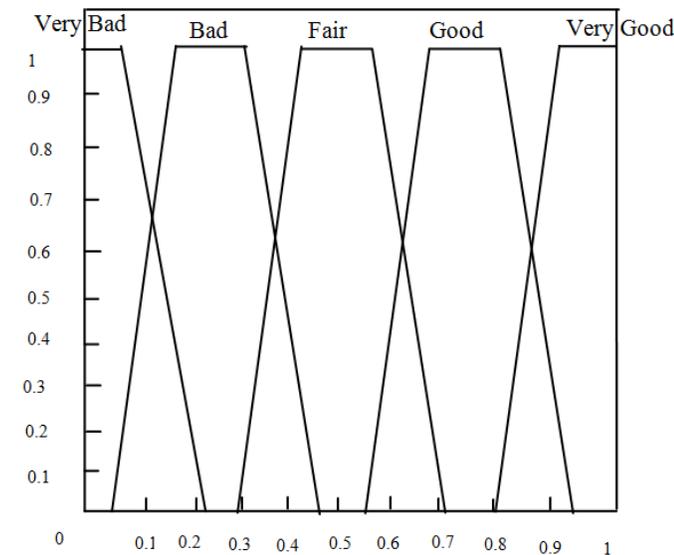

Fig. 6. Output Trapezoidal membership functions for ("VERY BAD","BAD","FAIR","GOOD","VERY GOOD")

V. RESULT AND DISCUSSION

A route selection criterion is based on fuzzy concept. The designed system is tested over Haryana route and alternate routes are considered from origin to destination. The program for developed system is written in programming language (PHP, MYSQL) and it is designed for two types of queries (general and special). In case of general query, the designed system returned the results on the basis of average score of PA and in case of special query; the average score of (PA + SA) is used to display results as shown in Table VI. The system users can view all alternate routes from origin to destination just by entering starting and ending point of journey as well as they can select optimal route for their journey. Four feasible routes and their descriptions are given here in Table I and Table V. Route1 and Route2 could be a route with heavy use of National Highway and the average score of primary and secondary attributes is 0.8 on Route1 as shown in Table VI which is the largest score among four feasible routes.

Fuzzy rules are used to specify the optimal route:

Rule 1:

IF	Travel distance is SHORT on Route1 AND Travel distance is LONG on Route2
THEN	Route1 is VERY GOOD and Route2 is very BAD

Rule 2:

IF	Distance is LONG and Congestion is LOW on Route1 AND Distance is SHORT and Congestion is VERY HIGH on Route2
THEN	Route1 is GOOD and Route2 is VERY BAD

TABLE VI. AVERAGE SCORE OF PA, SA AND (PA+SA) CORRESPONDING ROUTES

	PA Score	SA Score	(PA+SA) Score
Route1	0.9	0.8	0.8
Route2	0.6	0.5	0.5
Route3	0.4	0.4	0.4
Route4	0.4	0.4	0.4

It's quite clear that Route1 will be optimal route for general and special types of driver's queries. The average score of PA, SA attribute is 0.9, 0.8 respectively of Route1 and average score of (PA+SA) is 0.8 which is highly fuzzy score among all alternate routes, so it is recommended route for the driver. Route2 has the next highest score it will be the next recommended route. The designed system provides reliable result as compared to other existing system because almost all road attributes are considered here to assign score to each route.

VI. CONCLUSION AND FUTURE WORK

An intelligent route selection system is presented in this article. The system provides the optimum route for particular drivers to his/her preference. The concept of primary and secondary road attributes is discussed and a criterion for optimum route selection is set. The route selection criteria is

based on fuzzy logic in which output Trapezoidal membership functions for Route1, Route2, Route3 and Route4 are " GOOD", "FAIR", "BAD" and "BAD" respectively. The first output membership function shows the optimal route among all alternate routes. This vehicle navigation system will be helpful for drivers in decision making to select more precise optimal route. In future ORSVNS will be a part of more intelligent route selection system for transportation.

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