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ON THE CHOICE OF ROUTE

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ABSTRACT: Vehicular traffic congestion remains a major societal concern across the world with no visible signs of substantial reduction in the future. In this study, a new route choice model has been presented. The main parameters used in this model are the normalized resistance and normalized density of the routes carrying the traffic. Various scenarios have been implemented for different values of these parameters. Simulation results are presented which confirm that the proposed route choice model can be effectively applied to metropolitan traffic to reduce traffic congestion and driving time.

Keywords: Congestion, route choice model, normalized resistance, normalized density, driving time.

INTRODUCTION

In metropolitan cities traffic congestion is a serious problem. Growing economy results in the increase in number of vehicles which contributes in traffic congestion, particularly in Pakistan, which is one of the growing economies of the world. The ever growing number of vehicles leads to traffic congestion consequently results in road crashes, economic losses and increased travelled times. Moreover the traffic congestion creates environmental contamination and noise pollution.

The major metropolitan city of Pakistan is Karachi, where in 2011 there were more than 2.6 million vehicles and the number is growing rapidly (Urban, 2011). Even with the enforcement of transportation regulations, traffic congestion is being observed on a regular basis on many road segments that reduces the average traffic speed to 20-25 km/hr on typical work days. With no or little congestion, the average traffic speed goes up to 40-45 km/hr where 50 km/hr is the maximum allowed speed. Fixing the congestion problem will help utilize the transportation resources more efficiently and increase the throughput.

It is widely agreed that adding physical capacity will not keep up with the increasing traffic demands. Modern and efficient management of existing systems must be called upon to deliver improvements in transportation service productivity. Intelligent transportation Systems (ITS) uses technologies such as sensing, location, and communications, to manage transportation networks. Advanced traveler information systems (ATIS) and advanced traffic management systems (ATMS) use technologies such as advanced surveillance systems over a road network. Another example is digital sensing and communication between a control center and vehicles to monitor, manage and control traffic in a road network and to provide information and guidance to drivers in order to mitigate congestion and enhance safety.

In order to solve the traffic congestion problem, we first examine existing traffic models and then propose a solution. For deterministic modelling of traffic flow (Khan and Gulliver, 2019; Khan *et al.*, 2019) can be reckon. (Carlo, 2009) reviewed the state of the art in the analysis of route choice behavior within the discrete choice modelling framework, however, the models within this framework are complex for practical applications. Existing GPS devices only consider the inherent static characteristics of roads such as the length and speed limit to determine the shortest distance route for users. People are now more concerned with driving time than driving distance. However, in the downtown areas of a metropolitan city, especially at peak hours, the shortest time route is often different from the shortest distance route because of traffic congestion. The route choice model provides information based on traffic flow theory that is helpful in answering problems related to traffic resistance and density (Ni, 2016).

Traffic simulation, which attempts to describe how individual drivers select the best route at an intersection, relies on mathematical traffic flow models developed using traffic resistance and density. Traffic flow theory is of interest to traffic management for studying the relationship amongst the general characteristics of a traffic flow, i.e. traffic resistance and traffic density. For the purposes of determining the best route, a route choice model is implemented.

MATERIALS AND METHODS

Traffic resistance and traffic density are the primary physical attributes for traffic analysis. Traffic can be described using flow variables such as resistance, velocity, and density. The density of traffic is the number of vehicles that are present on a roadway per unit distance and is measured in veh/m. The resistance of traffic is a parameter which affects the smooth flow of the traffic and is measured in veh/m. Traffic resistance is a function of relative velocity and density. Traffic velocity can be expressed either as an average speed over a period of time, or as an instantaneous value at a single moment in time and is measured in m/s. Traffic flow is defined as the product of density and velocity and is measured in veh/s. The parameters that are normally used in the modelling and analysis of traffic flow are the normalized density and the normalized resistance. The normalized density is defined as the ratio of traffic density and the maximum traffic density. Similarly, the normalized resistance is the traffic resistance divided by its maximum value. Like the normalized density, the normalized resistance is a dimensionless quantity.

This study investigates a route choice model which helps to address the traffic congestion problem. The model uses the traffic resistance and density at an intersection to predict the route choice. This allows drivers to select the best route for their destinations based on using traffic resistance and traffic density. For instance, if there is construction on a route or an accident has occurred, using this model driver will know in advance the traveling time of that particular route. This model employs real time data compared to current techniques for the shortest time route which do not use real time data. Furthermore, this model can be used to accommodate more vehicles on a road network.

A route choice model is proposed for selecting the best route based on the normalized resistance and normalized density, the proposed model is based on the analogies with computer networks. A computer network is assumed as a road network and the data packets as vehicles. With an increase in the number of packets in a computer network, a transition from smooth flow to congestion occurs. Similarly, with a rise in the number of vehicles on a road network, congestion develops. An intersection acts as a router as the vehicles choose a path to their destinations. Based on normalized resistance and normalized density, a probabilistic model and analogous to computer networks is proposed for vehicles traffic flow at intersections. The model is presented below.

Consider an intersection with n number of routes. A route is defined as a choice a driver can make at an intersection. Let x_i denote the ith route, where$i = 1,2,3\ldots,n$, and let ρ_i and R_i denote the normalized density and normalized resistance of routex_i, respectively. The normalized density and the normalized resistance lie between 0 and 1. A driver choose route x_i based in the normalized density and normalized resistance with a probability $p(x_i)$, which is given by

$$p(x_i) = \frac{e^{-\rho(x_i)R_i}}{\sum_{i=1}^{n} e^{-\rho(x_j)R_j}}, \quad (1)$$

where

$$\sum_{i=1}^{n} p(x_i) = 1. \quad (2)$$

This model indicates that the probability of selecting a route depends on

1. Normalized resistance of a route,
2. Normalized density of a route.

In other words, the probability of selecting a route is higher for less resistant, and less normalized dense routes. Moreover, if the normalized resistance or normalized density of a route increases, then the probability of selecting that route will be reduced.

The traffic flow can be classified as free flow or congested. Greenshields model (Ni, 2016) is the most widely used model for traffic velocity due to its simplicity and is given as

$$v(\rho) = v_m\left(1 - \frac{\rho}{\rho_m}\right). \quad (3)$$

Where ρ is the traffic density at a given time, ρ_m is the maximum traffic density, and v_m is the maximum traffic velocity. According to (3), the velocity of traffic is higher at lower traffic densities and vice versa.

RESULTS AND DISCUSSION

The results of the proposed model for route choice of drivers are presented in this section, various scenarios are considered, such that four legged intersections and two legged intersections and results are presented using MATLAB. In the first scenario driver arrives at the intersection and has the option to choose one of the four routes labelled as x_1, x_2, x_3 and x_4 as in Figure 1. Route X_1 has a variable resistance from 0 to 1 whereas X_2, X_3 and X_4 has a constant resistance of $0.8, 0.5$ and 0.2. The same scenarios are tested for two different values of normalized density such that 0.5 and 0.7. The simulation parameters are shown in Table 1.

Table 1: Simulation parameters for 0.5 and 0.7 normalized densities.

Route	Normalize Resistance	Normalized Density	Normalized Density
X_1	$0-1$	0.5	0.7
X_2	0.8	0.5	0.7
X_3	0.5	0.5	0.7
X_4	0.2	0.5	0.7

Figure 2 shows that the increasing the normalized resistance of route X_1results in a decrease in the probability of choosing it. Route X_1 becomes the first priority when it has the lowest normalized resistance, i.e $R_1 \leq 0.2$. As the value of R_1 exceeds $0.2, 0.5$ and 0.8, the priority of choosing the route X_1 gets lowered to the second, third and forth respectively. The maximum and the minimum probabilities of selecting individual routes are also shown in Table 2. Note that increasing R_1 results in decrease in $p(X_1)$ and an increase in the probabilities of choosing other routes. Therefore, the maximum probability of routes X_2, X_3 and $X_4$are achieved when the normalized resistance in route X_1 is maximum, such that $R_1 = 1$ and the minimum probability of routes X_2, X_3 and X_4 are achieved when the normalized resistance on Route X_1 is minimum, such that $R_1 = 0$.

Figure 1: An Intersection with four legs.

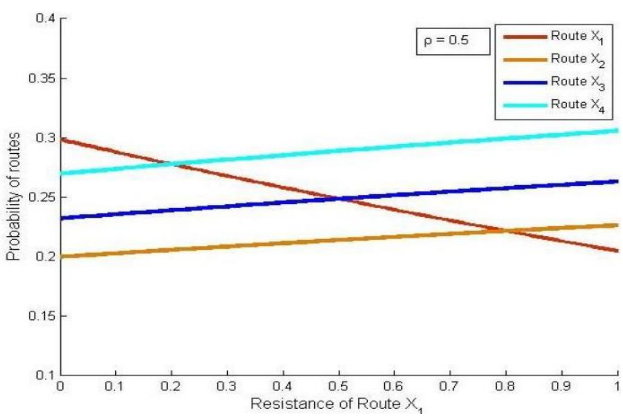

Figure 2: The effect of changes in the normalized resistance of Route X_1 on the route Probabilities with normalized density = 0.5.

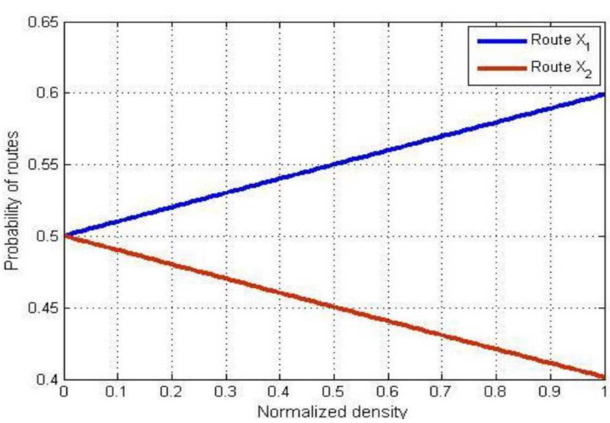

Figure 3: The effect of changes in the normalized resistance of Route X_1 on the route probabilities with normalized density = 0.7

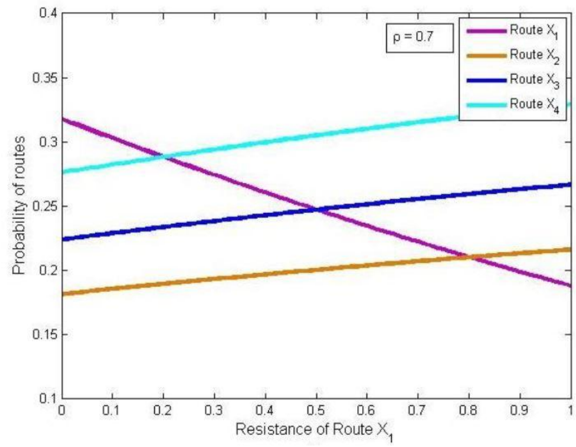

Figure 4: The effect of change in Normalized Density in the route probabilities.

Figure 4 show the probability of two routes X_1 and X_2 against the normalized density. When the normalized density increases, driver priority of route 2 decreases because it has higher route resistance as compared to route X_1. The driver priority for choosing the route X_1 is higher than route X_2 because as the normalized density is increasing in Route X_2, the probability of route X_2 is decreasing as we can clearly see in Figure 4, and at the same time probability of Route X_1 is increasing. The probabilities of selecting the routes are given in Table 4 for selected values of the normalized density.

Table 2 shows the maximum and minimum probabilities of selecting individual routes. The probability of selecting route R_1 achieves its maximum probability when $R_1 = 0$, while at the same time the probability of selecting the other routes become minimum. Also, when$R_1 = 1$, the probability of selecting route R_1 becomes minimum and the probability of selecting the other routes achieve their maxima.

Table 2: Maximum and minimum probabilities of selecting individual routes.

Route	Maximum Route Probability with normalized Density = 0.5	Minimum Route Probability with normalized Density = 0.5	Maximum Route Probability with normalized Density = 0.7	Minimum Route Probability with normalized Density = 0.7
X_1	0.2982	0.2049	0.3179	0.1880
X_2	0.2264	0.1999	0.2162	0.1816
X_3	0.2631	0.2233	0.2667	0.2240
X_4	0.3056	0.2698	0.3291	0.2764

In the second scenario an intersection with two routes is considered. A driver arrives at the intersection and has the option to choose one of the two routes, labelled as X_1 and X_2. Route X_1 has normalized resistance of 0.3 and route X_2 has normalized resistance of 0.7. The normalized density of both routes vary from 0 to 1 as shown in Figure 4. The simulation parameters are shown in Table 3.

Table 3: Simulation parameters.

Description	Value
Normalized resistance for route $\boldsymbol{X_1}$	0.3
Normalized resistance for route $\boldsymbol{X_2}$	0.7
Normalized density for $\boldsymbol{X_1}$ and $\boldsymbol{X_2}$	$0-1$

Table 4 shows the probability of selecting routes X_1 and X_2, at selected values of the normalized density while keeping their normalized resistance values at 0.3 and 0.7, respectively. Route X_1 has the probability of 0.5300 given that route X_2 has a probability of 0.4700 at 0.3 normalized density. Similarly the normalized densities of 0.5, 0.7 and 0.9. The probabilities of route 1 are 0.5498, 0.5695 and 0.5890, respectively, so the probabilities of route X_2 are 0.4502 and 0.4110, respectively.

Table 4: Probability of selecting route $\boldsymbol{X_1}$ and $\boldsymbol{X_2}$.

Normalized density	Probability of Route X_1	Probability of Route X_2
0.3	0.5300	0.4700
0.5	0.5498	0.4502
0.7	0.5695	0.4305
0.9	0.5890	0.4110

Conclusion: A route choice model has been implemented based on the normalized resistance and the normalized density. Several scenarios were implemented using this model to verify its usefulness. The results obtained show that the traffic density has a significant impact on the choice of a route, but it is not the only deciding factor in this model. Traffic resistance is also significant for selecting the best route for drivers. Based on the information obtained, drivers can decide the best route for their destination. Simulation results were presented which show that this model is efficient, useful, and can be implemented in a metropolitan-scale city. In the future, it can be implemented in intelligent transportation systems (ITS), which are communication systems between vehicles and the outside world. Vehicles can then make decisions by communicating with RSU's (road side units) using OBU's (on board units).

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