On the Choice of Route

by

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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 project, 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.

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Dedication

This work is dedicated to my mother, whom I love so very much, this is for you mother.

Chapter 1: Introduction

Traffic congestion is a very serious problem in large cities. With the number of vehicles increasing rapidly, especially in cities where the economy is growing, the situation is getting worse. People in metropolitan cities suffer from traffic jams every day. This is particularly serious in developing countries such as Pakistan. Further, the ever-growing increase in vehicles leads to road congestion, and consequently results in increasing road accidents, economic losses, and extended delivery times, both for goods and passenger traffic in logistics chains. Traffic jams also create environmental contamination and noise pollution.

In Karachi, the major metropolitan city in Pakistan, there were more than 2.6 million vehicles in 2011, and the number is growing rapidly [1]. 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 only 20-25 km/h on typical work days. With no or little congestion, the average traffic speed goes up to 45-50 km/h where 50 km/h 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) use 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 [3].

In order to solve the traffic congestion problem, we first examine existing traffic models and then propose a solution. 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 [2].

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.

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/s^2. Traffic resistance is a function of relative velocity and density. Traffic velocity can be expressed either as an average 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 paramters 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 project investigates a route choice model to help 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 drivers 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.

The objectives of this project are to:

1. Implement a route choice model.
2. Evaluate the model using traffic resistance and density.
3. Determine the effect of a change in route resistance on a particular route compared to the resistance of other routes.
4. Determine the effect of a change in route density on a particular route compared to the other route densities.

Chapter 2: Methodology

In this chapter we devise a route model that could be used to select the best route based on the normalized resistance and the normalized density. The traffic flow model is based on analogies with computer networks [4]. A computer network is assumed as the road network and 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, and analogous to computer networks [4], a probabilistic model is proposed for vehicles traffic flow at an intersections. The model is presented below.

Consider a traffic network comprising n routes at an intersection. A route is defined as a choice a driver can make at an intersection. Let X_i denote the ith route, where $i = 1, 2, \cdots, n$, and let $\rho(i)$ and R_i denote the normalized density and the normalized resistance of Route X_i, respectively. The normalized density and the normalized resistance lie between 0 and 1. Based on the instantaneous normalized densities and the normalized resistances of the routes at an intersection, a driver chooses the Route X_i with probability $p(X_i)$. The probability of choosing Route X_i is

$$p(X_i) = \frac{e^{-\rho(i)\, R_i}}{\sum_{j=1}^{n} e^{-\rho(j)\left(R_j\right)}}, \qquad (1)$$

where

$$\sum_{i=1}^{n} p\,(X_i) = 1\,. \qquad (2)$$

Consider the case where there are two routes at an intersection. The probabilities of selecting the routes are

$$p(X_1) = \frac{e^{-\rho(1)(R_1)}}{e^{-\rho(1)(R_1)} + e^{-\rho(2)(R_2)}} \qquad (3)$$

and

$$p(X_2) = \frac{e^{-\rho(2)(R_2)}}{e^{-\rho(2)(R_2)} + e^{-\rho(1)(R_1)}} \quad (4)$$

where R_1 and R_2 are the traffic resistances of routes X_1 and X_2, respectively, and

$$p(X_1) + p(X_2) = 1\ . \quad (5)$$

This model indicates that the probability of selecting a route depends on 1) normalized resistance of a route, and 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. Greenshield's model is the most widely used model for traffic velocity due to its simplicity and is given by [5]

$$V(\rho) = V_m\left(1 - \frac{\rho_t}{\rho_m}\right) = V_m(1 - \rho), \quad (6)$$

where ρ_t is the traffic density at a given time, ρ_m is the maximum traffic density, ρ is the normalized traffic density, and V_m is the maximum traffic velocity. According to (6), the velocity of traffic is higher at lower traffic densities and vice versa.

Figure 1 shows the trend of traffic flow against the normalized density of a route. The maximum velocity used is V_m = 25 m/s (90 km/h). The maximum traffic density is ρ_m = 0.25 veh/m. As evident from the figure, the traffic flow increases initially as the normalized density increases. As the normalized density increases beyond 0.5, the traffic flow starts to decrease. The normalized density at which the traffic flow achieves its maximum is termed the critical density. The traffic is considered to be free flow when ρ < 0.5 and congested when ρ > 0.5.

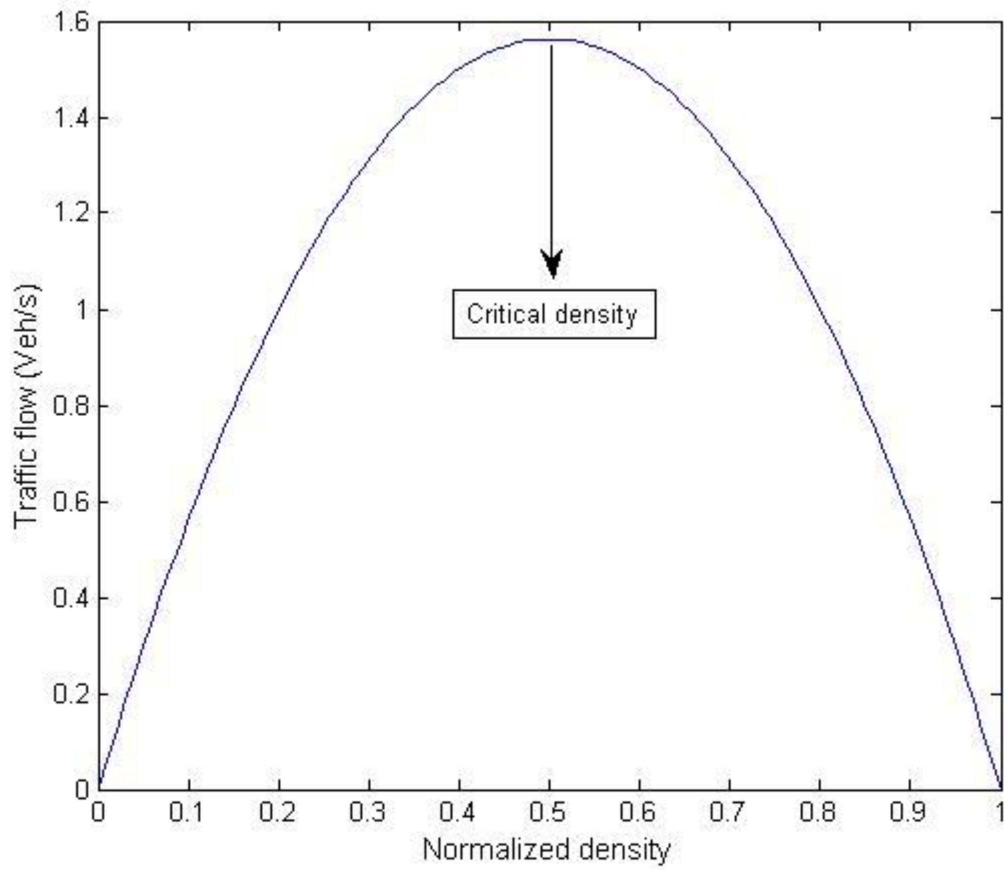

Figure 1: Traffic density versus flow using Greenshield's model.

Chapter 3: Results

In this chapter, we evaluate the proposed route choice model on various traffic scenarios and present the results. These results show that this model effectively chooses short time routes. In all scenarios, the route choice model uses normalized resistance, and normalized density parameters.

3.1 Example 1

Example 1 considers an intersection with four routes. A driver arrives at the intersection and has the option to choose one of four routes, denoted as X_1, X_2, X_3, and X_4 in Figure 2. Route X_1 has variable resistance from 0 to 1 and routes X_2, X_3, and X_4 have constant resistances of 0.8, 0.5 and 0.2, respectively. We test the same scenario for two different values of normalized density, i.e. 0.5 and 0.7. Figure 3(a) shows results for a normalized density of 0.5 while Figure 3(b) shows results for a normalized density of 0.7. Equations (1) and (2) are implemented in this example. The simulation paramters are shown in Table 1.

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

Routes	Normalized resistance	Normalized density in Figure 3(a)	Normalized density in Figure 3(b)
X_1	0 to 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: An intersection with four routes.

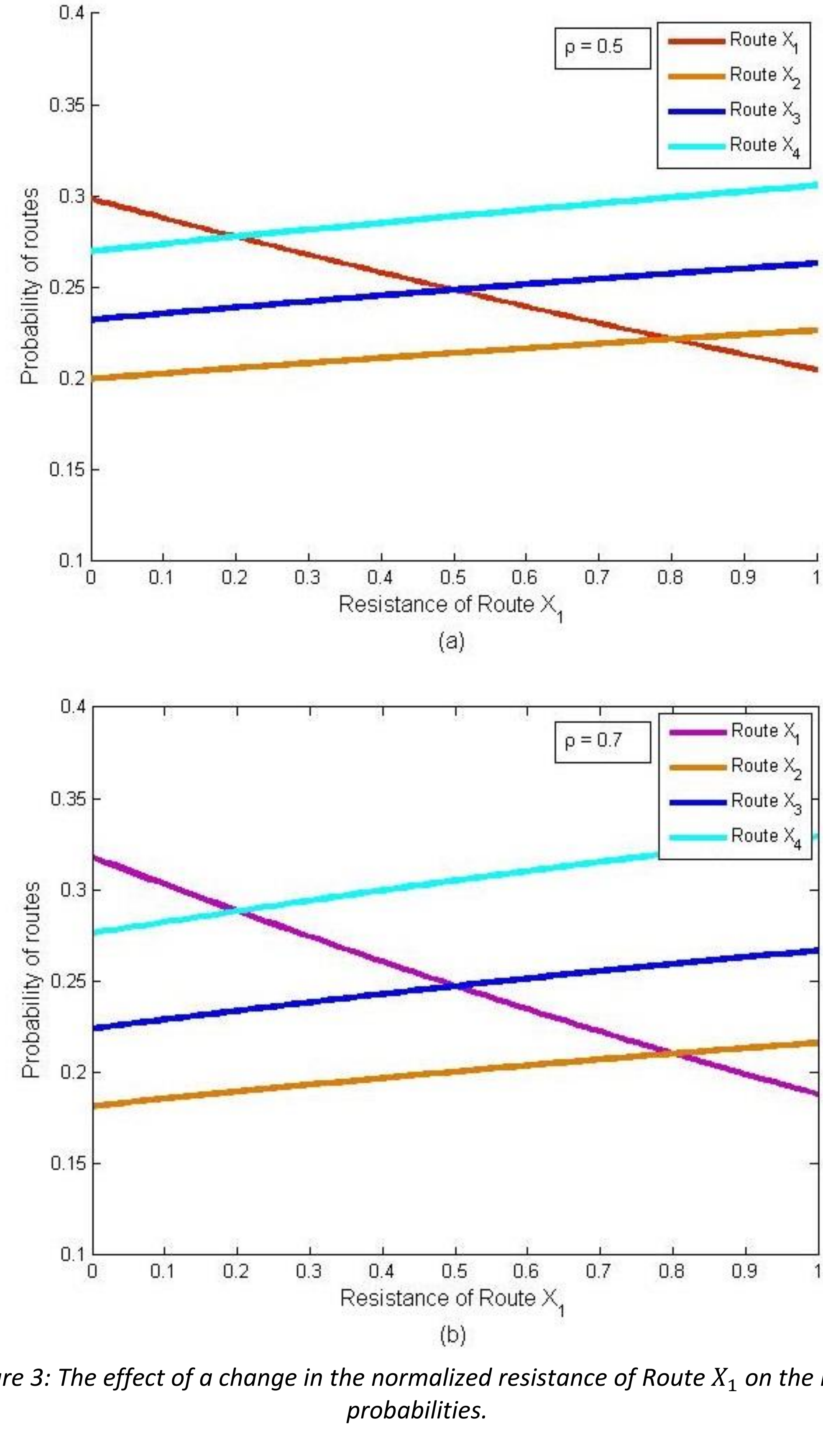

Figure 3: The effect of a change in the normalized resistance of Route X_1 on the route probabilities.

Figure 3 shows that increasing the normalized resistance of Route X_1 results 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 Route X_1 gets lowered to the second, third and fourth, respectively. The maximum and minimum probabilities of selecting individual routes are also shown in Table 2. Note that increasing R_1 results in a 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, i.e. R_1= 1 and the minimum probability of routes X_2, X_3 and X_4 are achieved when the normalized resistance in Route X_1 is minimum, i.e. R_1=0.

Table 2: The maximum and minimum route probabilities versus different values of normalized densities.

Routes	0.5 normalized density		0.7 normalized density	
	Maximum route probability	Minimum route probability	Maximum route probability	Minimum route probability
X_1	0.2982	0.2049	0.3179	0.1880
X_2	0.2264	0.1999	0.2162	0.1816
X_3	0.2631	0.2322	0.2667	0.2240
X_4	0.3056	0.2698	0.3291	0.2764

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

3.2 Example 2

Example 2 considers an intersection with two routes. A driver arrives at the intersection and has the option to choose one of two routes, denoted as X_1 and X_2. Route X_1 has a normalized resistance of 0.3 and Route X_2 has a normalized resistance of 0.7. The normalized density of both routes vary from 0 to 1 as shown in Figure 5. Equations (3), (4) and (5) are implemented in this example. The simulation parameters are shown in Table 3.

Table 3: Simulation parameters for Example 2.

Normalized resistance for Route X_1	0.3
Normalized resistance for Route X_2	0.7
Normalized density for routes X_1 and X_2	0 to 1

Figure 4: An intersection with two routes.

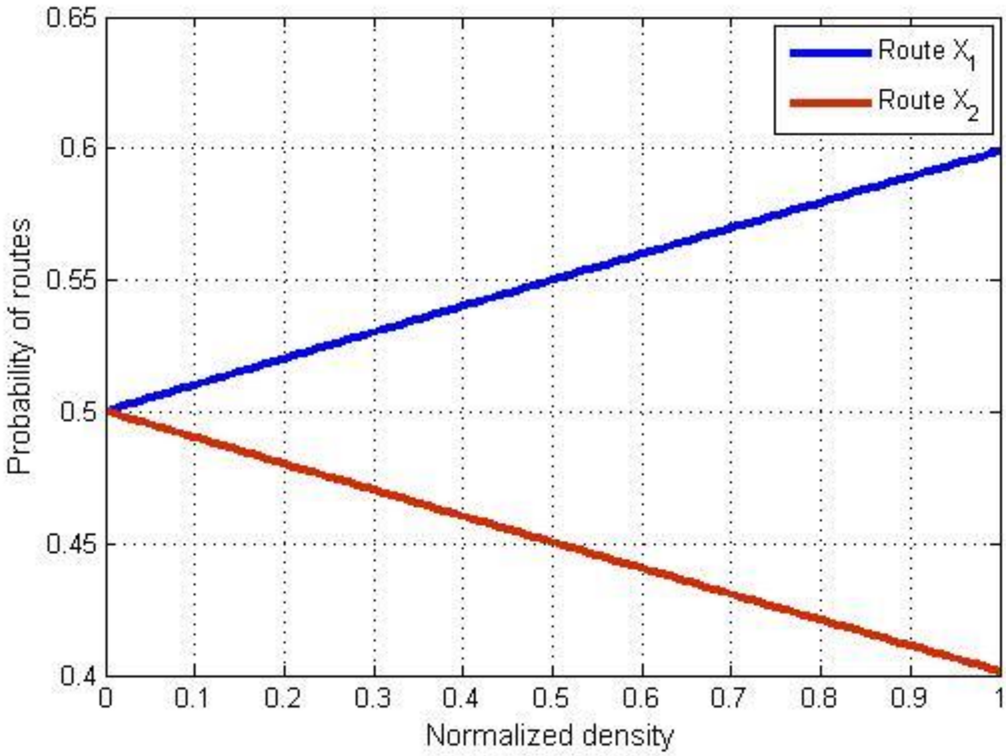

Figure 5: The effect of a change in the normalized density on the route probabilities.

Figure 5 shows the probabilities of the two routes X_1 and X_2 against the normalized density. When the normalized density increases, the priority of Route X_2 decreases because it has higher route resistance as compared to Route X_1. The priority for choosing 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 shown in Figure 5. At the same time, the probability of Route X_1 is increasing. The probabilities of selecting the routes are given in Table 4 for selected values of normalized density.

Table 4: The probability of selecting routes X_1 and X_2 for different values of normalized density.

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

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 a probability of 0.5300 and Route X_2 has a probability of 0.4700 at 0.3 normalized density. Similarly at normalized densities of 0.5, 0.7 and 0.9, the probabilities of Route X_1 are 0.5498, 0.5695 and 0.5890, respectively, and the probabilities of Route X_2 are 0.4502, 0.4305 and 0.4110, respectively.

3.3 Example 3

Example 3 again considers an intersection with two routes. A driver arrives at the intersection and has the option to choose one of two routes, denoted as X_1 or X_2. This example differs from Example 2 because the normalized resistance is varied from 0 to 1 in both routes X_1 and X_2, whereas the normalized density is 0.3 as shown in Figure 6. Equations (3), (4) and (5) are implemented in this example. Figure 6(a) shows the probability of Route X_1 and Figure 6(b) shows the probability of Route X_2. The simulation parameters are shown in Table 5.

Table 5: Simulations parameters for Example 3.

Normalized resistance for Route X_1	0 to 1
Normalized resistance for Route X_2	0 to 1
Normalized density for routes X_1 and X_2	0.3

The routes are equiprobable when they have 50% of the normalized resistance on their routes. If the probability of Route X_1 is increasing then the probability of Route X_2 is decreasing, and vice versa.

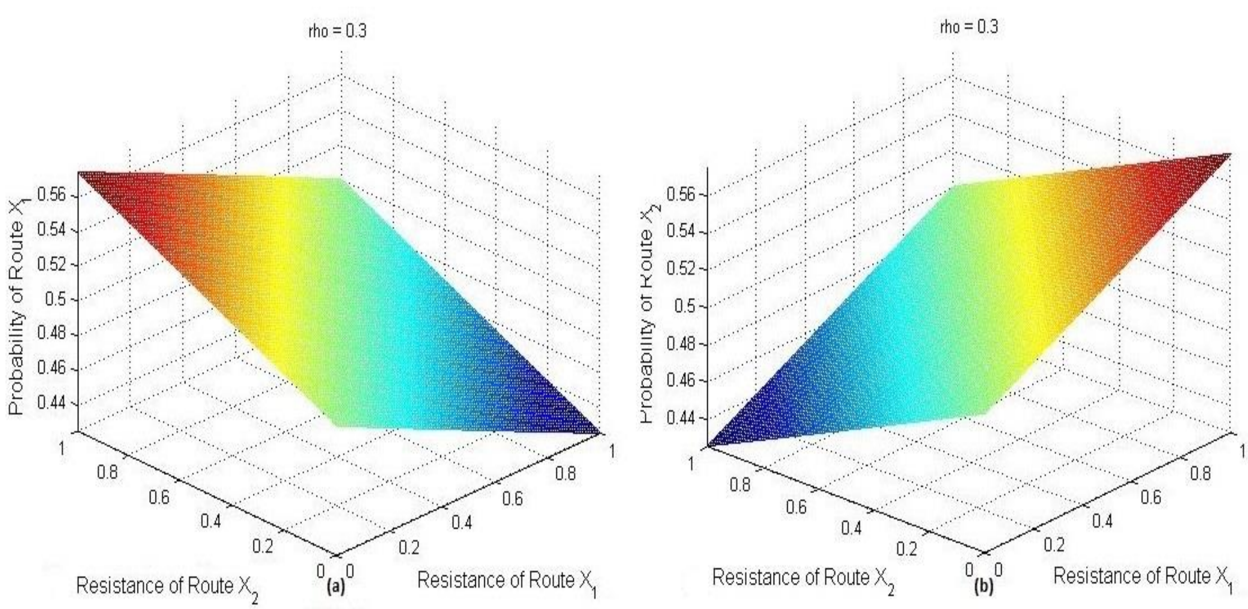

Figure 6: The probability of selecting a route versus the normalized resistance in the free flow region.

Figure 6 shows the behavior of the probabilities of selecting routes X_1 and X_2 versus normalized resistances with fixed normalized density. As the traffic resistance on a route increases, the priority of selecting that route decreases and results in a decrease in its selection probability. The maximum probability of Route X_1 is 0.5744 when there is minimum traffic resistance on Route X_1, i.e. R_1= 0 and maximum resistance occurs on Route X_2, i.e. R_2= 1. Likewise, the minimum probability is obtained for Route X_1 when there is maximum resistance on Route X_1, i.e. R_1= 1, and minimum traffic resistance on Route X_2, i.e. R_2= 0. The minimum probability of Route X_1 is 0.4256. Similarly, Route X_2 has priority when maximum resistance occurs on Route X_1, i.e. R_1= 1, and there is minimum resistance on Route X_2, i.e. R_2= 0, which results in the maximum probability of 0.5744. It is concluded that for a fixed normalized density, the driver priority depends on the traffic resistance. The minimum and maximum probabilities of selecting routes X_1 and X_2 are given in Table 6.

Table 6: The maximum and minimum probability for routes X_1 and X_2 for 0.3 normalized density.

Maximum probability for Route X_1	0.5744
Maximum probability for Route X_2	0.5744
Minimum probability for Route X_1	0.4256
Minimum probability for Route X_2	0.4256

3.4 Example 4

Example 4 again considers an intersection with two routes. A driver arrives at the intersection and has the option to choose one of two routes, denoted as X_1 or X_2. This example differs from Example 2 because the normalized resistance is varied from 0 to 1 in both routes X_1 and X_2, whereas the normalized density is 0.5 as shown in Figure 7. Equations (3), (4) and (5) are implemented in this example. Figure 7(a) shows the probability of Route X_1 and Figure 7(b) shows the probability of Route X_2. The simulation parameters are shown in Table 7.

Table 7: Simulations parameters for Example 4.

Normalized resistance for Route X_1	0 to 1
Normalized resistance for Route X_2	0 to 1
Normalized density for routes X_1 and X_2	0.5

Both routes are equiprobable when they have 50% of the normalized resistance on their routes. If the probability of Route X_1 is increasing then the probability of Route X_2 is decreasing, and vice versa.

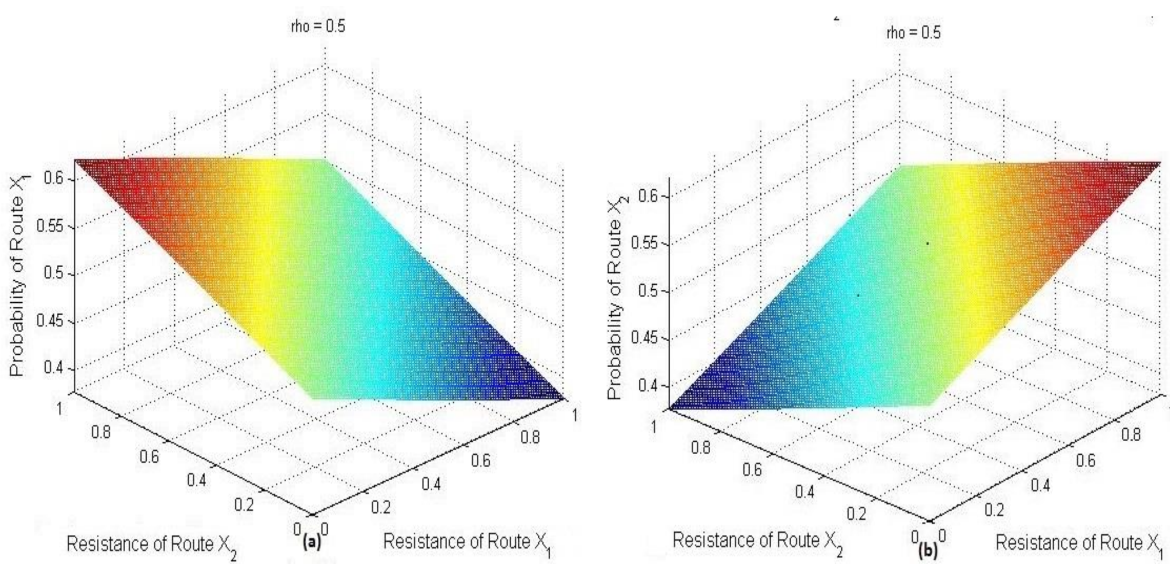

Figure 7: The probability of selecting a route versus the normalized resistance with critical density.

Figure 7 shows the probabilities of selecting routes X_1 and X_2 against their normalized resistances with fixed normalized density. As the traffic resistance on a route increases, the probability of selecting that route decreases. The maximum probability of Route X_1 is 0.622 when there is minimum traffic resistance on Route X_1, i.e. R_1= 0 and maximum resistance occurs on Route X_2, i.e. R_2= 1. Likewise, the minimum probability is obtained for Route X_1 when there is maximum resistance on Route X_1, i.e. R_1= 1, and minimum traffic resistance on Route X_2, i.e. R_2= 0. The minimum probability of Route X_1 is 0.378. Similarly, Route X_2 is priority when maximum resistance occurs on Route X_1, i.e. R_1= 1, and there is minimum resistance on Route X_2, i.e. R_2= 0, which results in the maximum probability of 0.622. The minimum and maximum probabilities of selecting routes X_1 and X_2 are given in Table 8.

Table 8: The maximum and minimum probability for routes X_1 and X_2 for 0.5 normalized density.

Maximum probability for Route X_1	0.622
Maximum probability for Route X_2	0.622
Minimum probability for Route X_1	0.378
Minimum probability for Route X_2	0.378

Tables 6 and 8 show that the normalized density plays an important role in determining the maximum and minimum probabilities of selecting a route. Specifically, increasing the normalized density from 0.3 to 0.5 results in a larger difference between the maximum and minimum probabilities of selecting a route.

3.5 Example 5

Example 5 again considers an intersection with four routes as shown in Figure 2. A driver arrives at the intersection and has the option to choose one of four routes, denoted as X_1, X_2, X_3, and X_4. Route X_1 has the normalized resistance varying from 0 to 1 and the other routes X_2, X_3 and X_4 have constant normalized resistances of 0.8, 0.5 and 0.2, respectively. In contrast to Example 1, the normalized density of all routes is varied from 0 to 1. Equations (1) and (2) are implemented in this example. The simulation parameters are shown in Table 9.

Table 9: Simulation parameters for Example 5.

Traffic resistance for Route X_1	0 to 1
Normalized density for all routes	0 to 1
Probability for Route X_1	0 to 1
Traffic resistance for Route X_2	0.8
Traffic resistance for Route X_3	0.5
Traffic resistance for Route X_4	0.2

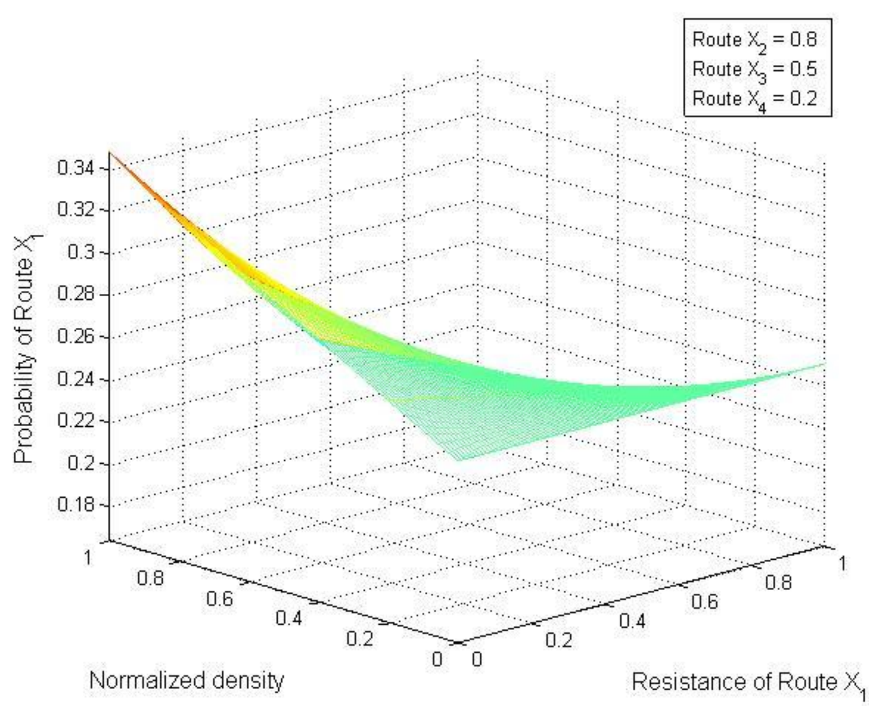

Figure 8: Route probability versus normalized resistance and normalized density.

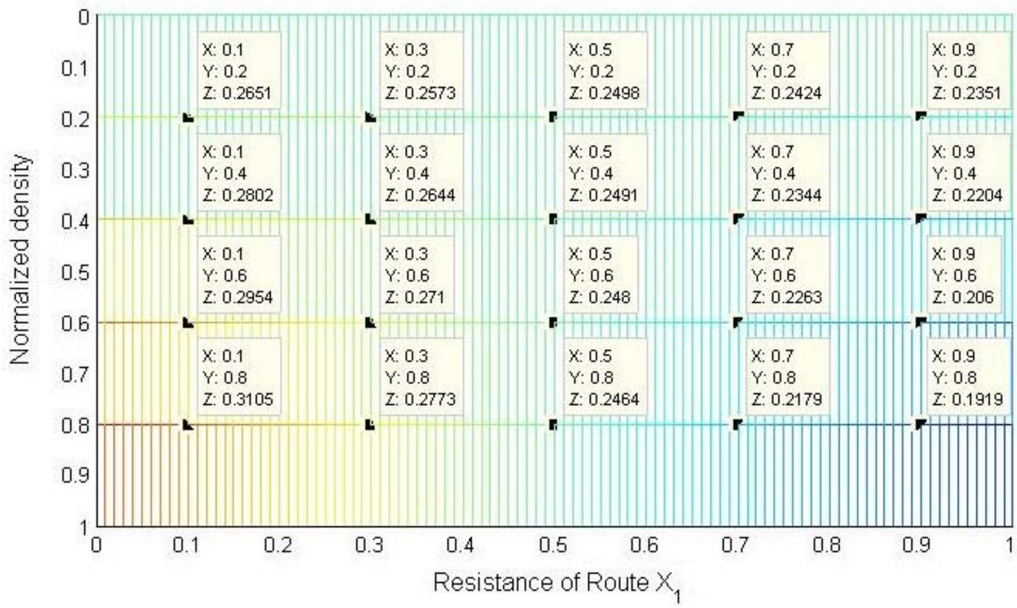

Figure 9: The probability of Route X_1 versus normalized density and normalized resistance.

Figures 8 and 9 show the difference between the maximum and minimum probabilities of selecting Route X_1 for different values of normalized density. When the normalized density is zero, all the routes have the same probability of being selected as expected from Equation (1). When the normalized density is increased from 0 to 1, the probability of selecting the route with the least normalized resistance increases. Likewise, the probability of selecting the route with the minimum normalized resistance decreases as the normalized density is increased. Therefore, the maximum probability and the minimum probability of selecting Route X_1 increases and decreases, respectively, by increasing the normalized density. Thus there is an increase in the difference between the maximum and minimum probabilities of selecting Route X_1 as shown in Table 10.

Table 10: The difference in the maximum and minimum probabilities of selecting Route X_1

Normalized density	Maximum probability of Route X_1	Minimum probability of Route X_1	Difference in probability of Route X_1
0	0.25	0.25	0
0.2	0.2651	0.2351	0.03
0.4	0.2802	0.2204	0.0598
0.6	0.2954	0.2060	0.0894
0.8	0.3106	0.1919	0.1196

Chapter 4: Conclusion and Future Work

In this project, a route choice model has been implemented based on the normalized resistance and 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 to 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 (ITSs), which are communication systems between vehicles and the outside world. Vehicles can then make decisions by communicating with Road Side Units (RSUs) using On Board Units (OBUs).

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