LOGI – Scientific Journal on Transport and Logistics
Vol. 11 No. 1 2020 DOI: 10.2478/logi-2020-0004
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Impact of V2V Communication on Eco-Route Choice

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Abstract: Usually, route choice is performed considering a single objective like considering a single object among travel time, emission, and travel distance. In this article, a methodology has been developed to find the eco-friendly route considering multi-objective- travel time, emission and travel distance. Pareto optimality and weighted product model are used for multi-objective optimization and route choice is done by Dijkstra's shortest path algorithm. Simulation software, AIMSUN is used to perform micro-simulation for collecting second by second vehicle speed and acceleration profile. Vehicle Specific Power (VSP) model is used to estimate emission. Emission at the traffic network can be significantly reduced by using the vehicle to vehicle communication. Using the V2V communication system, CO_2, NOx, CO, HC can be reduced up to 5.34%, 9.57%, 25.84%, and 3.67% respectively in route choice considering budget travel time and travel distance. The difference in route choice pattern has also found considering without and with V2V communication.

Keywords: Eco-route, optimization, V2V, travel time, travel distance

1. Introduction

With the social advance of civilization, technology and economic growth, transportation planners and traffic engineers no longer solely emphasis on congestion when resolving transportation hitches or optimization transportation systems. In recent years, the fact that road transportation negatively affects the well-being of the environment are gradually increased with the increase of the numbers of automobiles. According to the United States Environmental Protection Agency (USEPA), road transportation (automobiles, trucks, and buses) is recognized as the greatest source of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NOx) from the burning of fuel. Numerous studies have pointed out that these vehicle emissions clearly contribute to various health problems including cancer, cardiovascular and respiratory diseases and perinatal mortality [1]. As a major source of air pollution, traffic emission contributes considerably to the exhaust of CO, CO_2, NOx, and HC in metropolitan areas. Transportation account for 28% of energy use and surface transportation accounts for 40% of annual emission [2]. Transportation is also a vital source of greenhouse gas emissions which leads irreversible anthropogenic global warming. The climate changes and damage costs could be catastrophic concerning the ecological degradation in a long run. Establishing strict energy policy, developing public transport system, promoting electric vehicles have been adopted widely for low-carbon transportation solutions. With the development of intelligent transportation system (ITS), eco routing has been exposed as a promising strategy to reduce emissions.

In the last decade, remarkable advances in road traffic emission models have been achieved with the rapid growth of comprehensiveness, complexity, and accuracy [3,4]. These advances provide numerous studies combining road transportation modeling with emission modeling emerge in the field of environmentally sustainable road transport research. Transport route choice modeling with emission is a key component of the integrated modeling. The existing signal system mainly focuses on reducing traffic congestion rather than traffic emission. The high rate of emission is accounted for higher speed fluctuations and frequent stops at intersection [5]. Stevanovic et al. suggested that the best flow of traffic in terms of fuel consumption and emission is the one with the fewest stops, shortest delays and moderate speeds maintained throughout the commute [5]. On the other hand, some studies find out that the time minimization path often also minimizes energy and emission [6] and others point out that the shortest time path is not good for emission perspective [7]. In this article, we use Vehicle to Vehicle communication to maintain optimal speed to avoid unnecessary acceleration in the arterial route network. Previous studies carried out on emission model, route choice and V2V communication system, but there is no study has been found to combined all point- emission estimation, route choice, V2V communication, optimization and comparison. To find out those question, this study is done.

2. Objectives

Vehicle to Vehicle communication helps to observe other vehicles' speed profiles within an observation range to reduce acceleration fluctuation and decide the optimal speed and this optimal speed will decrease emission. Usually, route choice is performed considering a single objective like considering a single objective among travel time, emission and travel distance. In this study, try to find out which route is more eco-friendly considering multi-objective- travel time, emission and travel distance. The difference of route choice pattern also studies considering without and with the V2V communication system considering a single object as well as multi-objects. Pareto optimality and weighted product model used for multi-objective optimization. For single objective route choice, Dijkstra’s shortest path algorithm is used considering travel time, travel distance and travel emission.

3. Methodology

The AIMSUN simulation software is used to create a traffic network and traffic simulation. Ten alternative routes from the same origin and destination in this network for route choice. The network is shown in Fig.1.

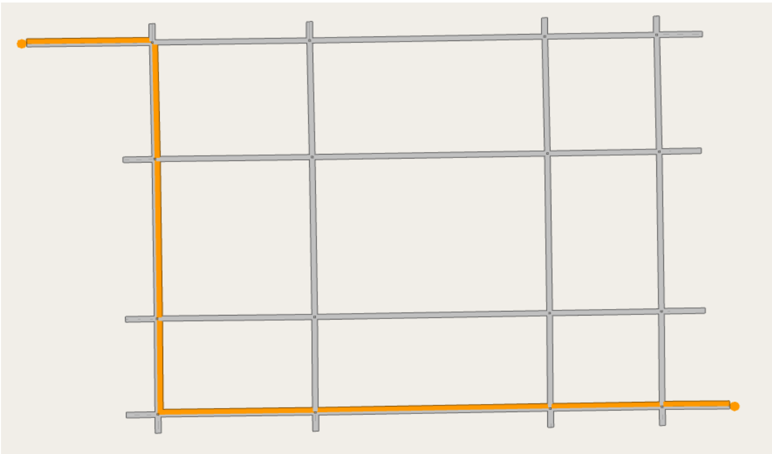

Fig. 1 Network consider in AIMSUN for simulation. Source: author

3.1 Vehicle to Vehicle Communication

Vehicle to vehicle communication algorithm is also incorporated in this software. Read the state of the vehicle and that of the proceeding vehicle (to check that the two are within the maximum communication range of the system and read the information that would be transmitted between the two such as position, speed, and acceleration) in this research we use 400 meters as a communication range. Modify the behavior parameters of the vehicle to emulate the transition from human to machine control. Control the speed of the vehicle of a vehicle during the simulation.

$$a_d = k_3 a + k_2 e_v + k_1 e_x \text{ , } k_1, k_2, k_3 > 0 \quad (1)$$

where: $\boldsymbol{a_d}$ is the acceleration that the follower should apply; a is the acceleration of the leader; $\boldsymbol{e_v}$ is the velocity error, equal to the relative speed between leader and follower; $\boldsymbol{e_x}$ is the clearance error, equal to the difference between the desire clearance and the clearance; $\boldsymbol{k_1}$,$\boldsymbol{k_2}$, $\boldsymbol{k_3}$ are controller feedback loop gains for acceleration a, velocity $\boldsymbol{v_x}$ and clearance error $\boldsymbol{e_x}$.

3.2 Emission Calculation

Speed and acceleration profiles for each vehicle are collected from AIMSUN simulation and those are used for emission calculation. Vehicle Specific Power (VSP) [8] model is used to emission calculation in the network.

$$VSP = v[1.1a + 9.81 * grade\,(\%) + 0.132] + 0.000302 * v3 \tag{2}$$

where: *v* is vehicle speed [m/s]; *a* is vehicle acceleration [m/s2]; *grade (%)* is vehicle vertical rise divided by slope length.

4. Results

Traffic emission at the traffic network can be significantly reduced by using the vehicle to vehicle communication. It can reduce acceleration fluctuation and gain optimal speed in the traffic network. CO_2 is the major element of vehicle emission. The effect of acceleration and speed on emission is shown in Fig. 2. The emission level is significantly higher during acceleration than a declaration. With the increase of speed, emission gradually increases up to a certain speed then emission gradually decreases with the increase in speed. Acceleration has been proved to be the most sensitive parameter to vehicle fuel consumption as well as emission. Using the V2V communication system, CO_2 can be reduced up to 5.34% as well as NOx, CO, HC can be reduced up to 9.57%, 25.84%, and 3.67% respectively. Table 1 shows the effect of the V2V communication system in the traffic network.

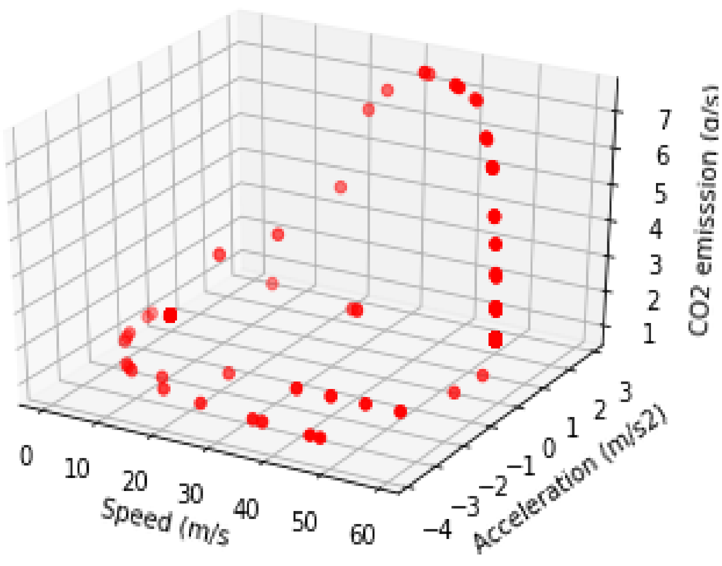

Fig. 2 Effect of acceleration and speed on emission. Source: author

Usually, route choice is performed considering a single objective like considering a single object among travel time, emission, and travel distance. In this research, Dijkstra’s shortest path algorithm is used for single object consideration and Pareto optimization as well as weighted product model are used for multi-objective decision-making route choice in the traffic network.

Table 1 % of emission reduction using V2V communication system compare to without V2V communication system. Source: author

Pollutant items	Emission reduce
NOx	9.57%
HC	3.67%
CO	25.84%
CO_2	5.34%

4.1 Single Objective-Dijkstra's Algorithm

Dijkstra's algorithm is an algorithm for finding the shortest paths between origin and destination in a network considering link cost. The link cost is calculated considering a single object among travel time, emission and travel distance.

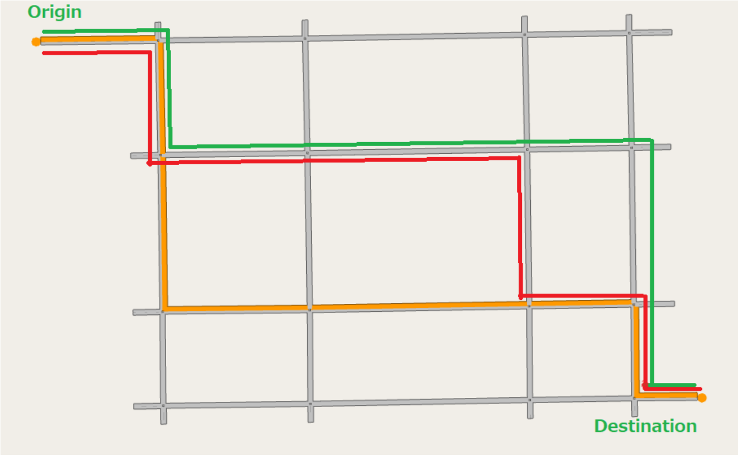

Fig. 3 Route choice without V2V communication, red = travel time, orange = travel distance, green = less emission. Source: author

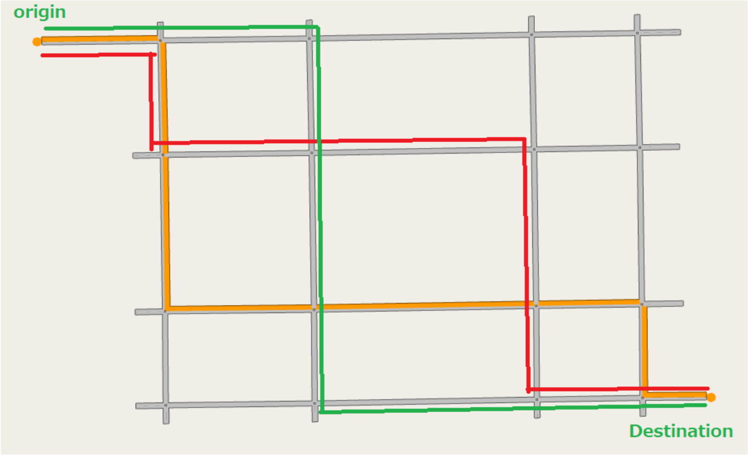

Fig. 4 Route choice with V2V communication, red = travel time, orange = travel distance, green = less emission. Source: author

Fig. 3 and Fig. 4 are shown that the fastest route as well as shortest path are not an eco-friendly route in a network for without and with the V2V communication system. The shortest path according to distance, travel time and eco are also different for both cases.

4.2 Multi-objective

For multi-objective route choice, route choice is done considering optimization and this optimization is done considering all factors- distance, travel time and emission.

4.2.1 Pareto Optimization

In this optimization, factors are considered as the same weight to select an optimal route. In Fig. 5 and Fig. 6 are shown different route choices for both cases. Three optimal routes are found without V2V communication system and two routes are found the optimal route for with V2V communication system. It is also found that about 13% emission can be reduced with V2V communication in Pareto optimization compare to without V2V communication.

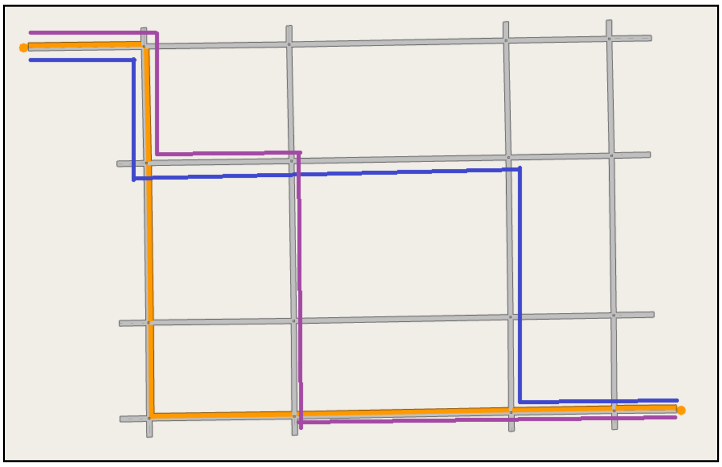

Fig. 5 Three optimal route choice without V2V communication in pareto optimization. Source: author

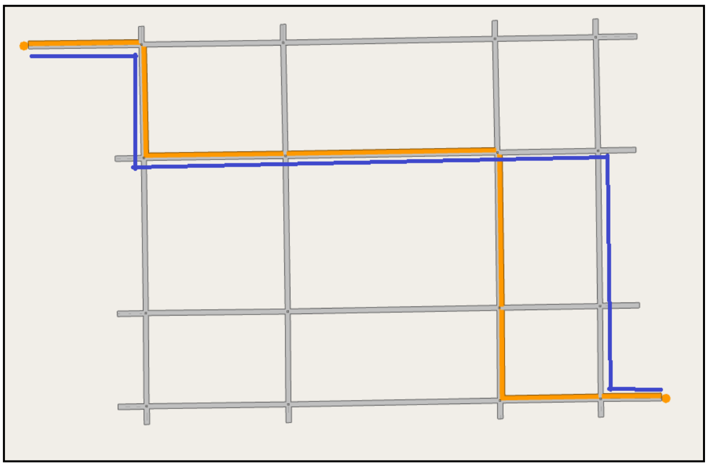

Fig. 6 Two optimal route choice with V2V communication in pareto optimization. Source: author

4.2.2 Weighted Product Model

In this method, each decision alternative is compared with the others by multiplying the number of ratios, one of each decision criterion. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion.

In this research, the weight of travel time, travel distance and CO_2 emission are changed according to traveler demand and route are estimated. We consider ten cases for different weights of travel time, travel distance and CO_2 emission which are shown in Table 2.

As an example, considering, Travel time-0.25, travel distance=0.25, CO_2 emission= 0.50, best route are shown in Fig. 7 and Fig. 8 for without the V2V communication system and with the communication system. Route choices are different for without and with V2V communication system in the network.

About 6% emission can be reduced with the V2V communication system in route choice considering 0.5 weigh of CO_2 emission, 0.25 for each weight of travel distance and travel time compare to the same consideration without V2V communication system in the network.

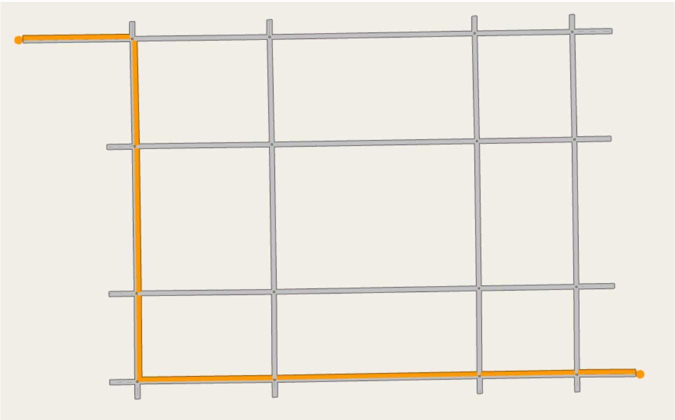

Fig. 7 Route choice without V2V communication. Source: author

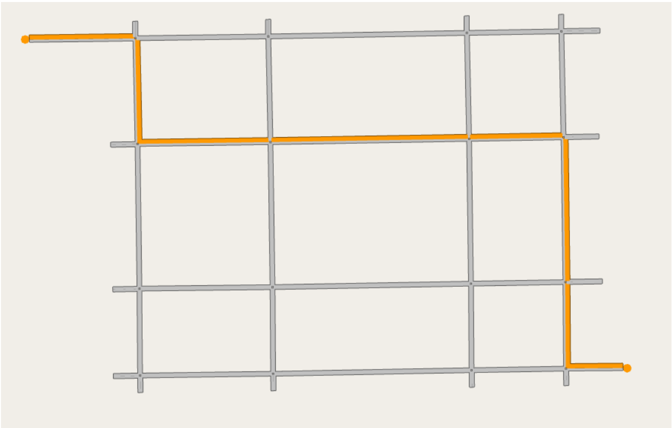

Fig. 8 Route choice with V2V communication. Source: author

Using the weighted product model, the traveler can select route choice their route with the given importance on travel time, travel distance and emission.

Table 2 Different weight of each objectives. Source: author

Case type	Travel time	Travel distance	CO_2 emission
Case-1	0.5	0.0	0.5
Case-2	0.0	0.5	0.5
Case-3	0.25	0.25	0.5
Case-4	0.15	0.1	0.75
Case-5	0.1	0.15	0.75
Case-6	0.2	0.2	0.6
Case-7	0.2	0.3	0.5
Case-8	0.2	0.2	0.6
Case-9	0.6	0.2	0.2
Case-10	0.2	0.6	0.2

5. Conclusion

The shortest path considering travel time and travel distance is not an eco-friendly route. Emission can be reduced by providing the V2V communication system. In the network, CO_2 is reduced by 5.34% using the V2V communication system. Using multi-objective optimization, we can get an optimal route which is more eco-friendly considering budget travel time and travel distance. Route choices are different for considering with and without the V2V communication system for a single object and multi-object route choice. V2V communication system has shown a more eco-friendly route choice. In this study, V2I in not consider in this study. Future study can go for evaluate for V2I on eco-route choice.

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