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Dynamic Modeling of traffic networks and analyzing drivers' behavior using game theories

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Abstract

Traffic can be considered one of the most exhausting parts of urban life today, which is the result of the accumulation of vehicles per unit of time in a particular intersection. Most of the urban highways have three passing lanes in the same direction, which include slow (lane 3) - medium (lane 2) and fast (lane 1) along with the emergency lane or park lane at the extreme right side of the road. In this research, 20 experts in the field of traffic were interviewed verbally about the variables affecting the volume of traffic and the relationships between them, and modeling was done with a causal diagram in VENSIM software. Then, 20 drivers were verbally surveyed about the fastest lane except the emergency lane during peak traffic conditions on the inner city highways, and all of them (one hundred percent of the sample population) considered the fast lane to be the fastest lane. By using the normal form of the theory of games - limited two-player games and a criterion - the equilibrium point of the game was obtained. The balance point in this game was the selection of the slow lane (lane 3) by each player who recorded the highest speed in it. The equilibrium point in the game showed that, contrary to the opinion of the surveyed drivers, the slow lane has the highest speed in traffic conditions.

***Keywords**:* dynamic modeling, traffic networks, driver behavior analysis, game theory

1- Introduction

Today, the transportation industry has a special place in advanced countries, and the main do's and don'ts related to those years have been taken into consideration. New scientific achievements in the transportation sector, which has a fundamental role in economic development, are the result of the efforts of transport and traffic experts and experts around the world (Aliahmadi et al., 2013).

Transportation networks in big developed cities have allocated a high percentage of the city's area, even up to fifty percent of it. By examining the aerial photos, it can be seen that large areas of these cities are dedicated to terminals, airports, parking lots, highways, railway stations, etc., which confirms the aforementioned issue of the extent of transportation and the need for sufficient facilities and resources on the other hand. In order to achieve and achieve the

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appropriate transportation networks, it is mentioned. Planning in transportation is started by choosing a project for design and construction or defining the problem and collecting statistics, analyzing the collected statistics, traffic forecasting process, estimating the effects of transportation facilities on the environment and usability, determining the costs and uses of the said project and Finally, the evaluation and provision of various solutions should continue (Nozari et al., 2019).

Design and construction in transportation are very closely related to each other. It follows the design of the general specifications of the transportation system, its efficiency, its compliance with existing laws and standards. In general, there are geometric design, pavement design, issues related to drainage and compliance of each of the values obtained from the design with the relevant standards, regarding the design of a road. Parking management, accident analysis, use of traffic signs, marking of crossings, checking the performance of intersections with traffic lights and without traffic lights, controlling the speed of vehicles, providing crossing lighting and finally controlling and managing crossing traffic are among the issues in this field (Nahr et al., 2021). Traffic can be measured by its most important quantitative variables, which are average vehicle speed and travel time. In such a way that the increase in traffic increases the travel time and decreases the average speed of the car. And because the travel time is affected by the travel distance, it is not a suitable option for measuring traffic. Therefore, the average speed of the car can be the best auxiliary variable to measure the volume of traffic (Gharachorloo et al., 2021).

It is obvious that in order to reduce novel wastage in traffic, save fuel consumption, reduce depreciation of cars, reduce accidents leading to injury, death, financial damage and environmental damage, including air pollution and noise pollution, there is a need for transportation system engineering in order to plan transportation and There is optimization of transportation systems (Nozari et al., 2016). Considering the importance of transportation and the congestion of transportation in the crossings that causes traffic, the necessity of traffic management in order to save time, cost and fuel on the one hand, and to reduce the harmful effects of traffic on the environment, it seems inevitable that in this research It can be based on the analysis of drivers' behavior in traffic and its correction through training and a practical basis for decision-makers and managers related to the field of traffic.

In this paper, the behavior of the drivers during the time interval of the peak traffic in the inner city highways and the choice of the route by the drivers and the decisions that the drivers make to choose the route and the perception they have about the progress of the route are the focus of the present study. Therefore, by using the system dynamics modeling tools, the dynamic traffic system is modeled and the mathematical model is examined and concluded using the game theory in normal form.

The structure of this paper is as follows. In the second part, the literature review is presented. In the third part, the research method is presented. In the fourth part, the data analysis will be reviewed and finally, the conclusion will be presented in the last part.

2- The importance and necessity of research

Traffic planning for the existing road network and making the necessary decisions for the proper and optimal use of the existing facilities is only possible based on information and perceptions that are close to reality. Therefore, the more the available information is in accordance with what is happening in the network, the better it is possible to identify defects, deficiencies and possible problems and take appropriate measures to correct them.

Various indicators and parameters that are used in traffic engineering, each expresses a special concept and can evaluate the traffic situation within its scope. Indicators such as crossing distance, capacity factor, peak hour coefficient, traffic volume and average speed, and such things, each according to its own definition, examine and evaluate the quantity or quality of traffic flow (Arani et al., 2017).

With dynamic modeling, each of these factors or all factors can be studied together. By using traffic flow models, it is possible to model the behavior and performance of the traffic flow, and using the obtained model, the characteristics of the traffic flow (density, traffic, average speed) can be obtained for different desired conditions for maximum traffic, for peak hours, etc. brought Then, based on the values obtained from the used model, appropriate policies and necessary decisions should be made to improve the traffic flow situation.

Many articles with the keywords of modeling and game theory can be found in a wide range of industrial, agricultural, socio-economic, etc. topics. There are very few articles with these titles in the fields of traffic. In 2020, Suryani et al., dynamic modeling of metropolises in order to provide transportation improvement policies, using vensim software, presented a model to describe urban transportation in the form of urban architecture reform, development of electronic services, computer park, and subway development. In this article, the information about the city of Tehran is used as an example. In 2015, Haghshenas et al. studied the dynamic modeling of the sustainable urban transportation system in order to improve traffic by presenting a dynamic model for the urban transportation system according to the concept of the sustainable urban transportation system and evaluated the dynamic complex nature of the urban transportation system and the impact of policies. This model is modeled with vensim software and data of Tehran metropolis. In 2020, Assaad and colleagues studied the behavioral modeling of drivers when encountering pedestrians using the logistic regression model in order to identify the effective factors in the occurrence of interaction between drivers and pedestrians and appropriate strategies to eliminate or reduce the effects of these factors in order to reduce accidents.

In 2008, Li addressed the modeling of urban traffic networks with the aim of researching the reasons for creating a major part of the traffic related to cities. In 2009, Dimitriou et al studied a complete course of game theory training and congestion rate of urban road networks for heterogeneous users based on travel time value period and real information of time imposition for daily substitution in multi-class traffic networks. In 2006, Bretti et al studied modeling for analyzing traffic networks with the aim of reducing traffic pollution in a large stochastic dynamic system. In 2009, Zhani analyzes the behavior of drivers of large and small (light and heavy) motor vehicles in developed countries and analyzes the behavior of the vehicle type along the way. In 2018, Benseghir et al. studied dynamic modeling for the process of traffic evacuation based on game theory based on a survey of pedestrians with the aim of applying game theory and dynamic modeling for the process of evacuation of pedestrians from traffic networks.

In 2020, Yin et al.'s dynamic modeling and cascade analysis of urban traffic networks introduce the average distance and hourly changes in traffic networks - the inherent characteristics of urban traffic and the characteristics of traffic and driving in it. In 2022, Chen et al.'s dynamic modeling of traffic networks on the outskirts of urban centers with a combination of Vickery theory and MFD deals with traffic on the outskirts of the city and testing how passengers can get to and from various corridors.

By reviewing the literature on the subject, it can be seen that four areas of dynamic modeling - traffic networks - driver behavior analysis and game theory have not been given attention by previous researchers at the same time. Traffic networks have always been modeled with other scientific tools such as queuing theory and few articles have been presented as dynamic modeling of traffic networks. Of course, in this context, attention should be paid to the term "dynamic" in modeling and its tools, such as causal-loop diagram and flow state diagram, so that modeling is not confused with other scientific tools. For example, there are studies in the field of simulating traffic networks with queuing theory or linear and non-linear models - probabilistic models, etc., which must be carefully considered in this field.

In the field of game theory, many researches have been done in the field of economy-management-environment-agriculture, etc., but no research in this field that deals with traffic networks using normal form and analyzing the behavior of drivers in traffic networks was found. The behavior of drivers has been more concerned with pedestrians-driving regulations-atmospheric conditions, etc., and no research was found in the field of game theory. According to what was investigated in this section, a significant gap between the current research and previous researches is observed, which is a reason for the innovativeness of the current research.

3- Research method

The volume of traffic, which is the message of a large number of cars at a limited and certain level of the crossing in a period of time, is modeled and analyzed as the most important and fundamental variable against other variables related to it by the scientific tool of causal-circular diagram and its feedback systems.

Vensim software in the field of dynamic modeling is one of these tools that are used in this research to analyze the variables related to traffic volume and their effects. Then experts are polled about the traffic flow of the highway lanes, then it is done by driving a test on a highway during the morning and evening peak traffic times, sometimes with two drivers and a length of 3.5 kilometers. Then the data is analyzed with game theory tools. According to the nature of the society and the subject under study, the sampling method in this research is judgmental (descriptive). According to the specialization of the subject under study, firstly, drivers with high driving experience who drive daily in traffic networks and at different times are questioned, and then the correctness of their judgment and experience is checked using the said driving test with the scientific tool of game theory, and the conclusion is presented.

In order to find the variables affecting traffic, first of all, 20 experts in the field of traffic, including traffic police officers, municipal traffic officers, civil engineers with a traffic orientation, and several university professors in the field related to various work records, are surveyed through a questionnaire and the relationships between them are discovered. Then causal and polarity diagrams between variables are created in Vansim software environment. It should be noted that in this article, we only deal with the relationships between traffic variables and the reasons for creating traffic, and not the study of traffic flow.

To ensure the correctness of the presented model, 150 traffic experts are surveyed for validation using a questionnaire to ensure the correctness of the variables and the relationships and polarity between them.

The research methodology is shown in Figure 1.

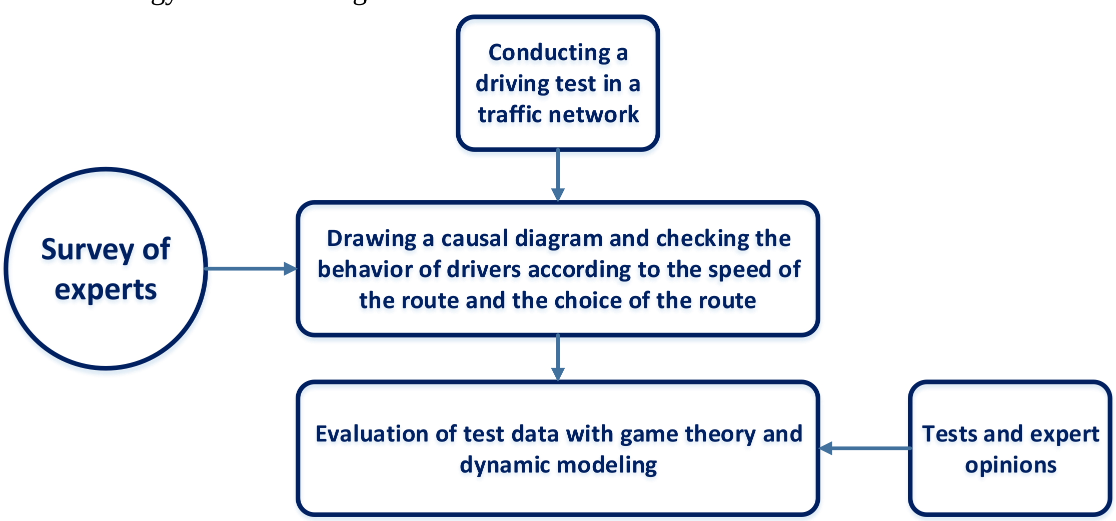

Figure 1: Research methodology

The strategy space is the chosen lines of the drivers, and the drivers are the players. Drivers are looking for a faster passage through the traffic network in a non-cooperative manner with the aim of choosing the fastest lane.

There are four lanes on the highway. The emergency lane is out of the game and the drivers have the right to choose it. The names of the speed lanes are as follows:

- Fast lane, lane 1
- The middle lane is lane 2
- Slow lane, lane 3

We name two drivers A and B, and the indices of the sub-names are their chosen lines. For example, A_1 means the choice of lane 1 by driver A or B_3 means the choice of lane 3 by player B.

This network modeling research is done in three stages:

- The first step is to find the variables influencing top traffic and their relationships with a survey of experts
- The second step is to draw the causal diagrams related to the experiment and its related feedback
- The third step is to examine the test data in the normal form of game theory to obtain the equilibrium point

In this research, dynamic modeling tools and techniques of game theory are used.

- **Dynamic modeling of systems**

For dynamic modeling in this article, the tools of dynamic traffic system and mathematical model using productivity matrix are used. Modeling with system dynamics technique is a method to analyze and simulate systems, which is called traffic system here. In the method of system dynamics, the relationships, analysis, and analysis of system components that have cause-effect relationships based on mathematical logic, time delays, and feedback loops can be used to create order in complex systems and help others understand and learn from this system. These diagrams are the best choice in quickly reaching a hypothesis about dynamic causes-inference and understanding the mental models of people or groups and relating important feedbacks that you believe are effective in the emergence of the problem. Causal-loop diagrams are important tools for showing the feedback structure of systems Causal diagrams consist of variables that are connected by arrows that show causal effects between variables. They also indicate important feedback loops in the diagram. The variables are connected by causal relationships which are shown as arrows, which have two types of positive and negative feedback.

- **Game theory**

The theory of games by modeling the behavior of drivers and checking its strategies against each other and analyzing the result of the game, which is the best result for drivers at the Nash point. The theory of games in normal form is one of the most common forms of a game so that N $(N \geq 2)$ players will participate in it. Each i-th player has x_i strategy (decision variable) $(1 \leq i \leq m_i)$. Xi may be bounded and discrete or unbounded and continuous from a space (E^n). It is assumed that the strategies (decision variables) are already known in the normal form for each player and his desirability or goal of decision is known as a function f_i. The function f_i for each player will be affected by his own decisions and those of other players.

$$F_i : f_i(X_1, X_2, \dots, X_i, X_n); \;\; 1 \leq \; i \leq m_i \quad (1)$$

Players make decisions simultaneously and without prior cooperation, while the goal of each of them is to optimize the relevant f_i. Therefore, the problem for the i-th player is to determine that strategy from the xi strategies that will lead to the optimal possible value for f_i. For N players in total, the problem involves reaching an equilibrium point ($Nash$) in such a way that a combination of strategies is determined in such a way that f_i is provided for all players as much as possible (in the best way) and deviation from that point causes losses for all or some of the players. It means that the choice of any strategy by the player except the strategy at the equilibrium point ($Nash$) will cause loss. The sum of simultaneous strategies for N players is given by equation 2.

$$X = \{x_1, x_2, \dots, x_i, \dots x_N\} \quad (2)$$

Therefore, an N-player game in the normal form, along with the objective functions $f_1, f_2, \dots, f_i, and \dots f_N$ is shown as relation 3.

$$P_N = P_N = \{N \, ; \, X_1, X_2, \dots, X_i \dots, X_N \, ; \, X \, ; \, f_1, f_2 \, \dots, f_i, \dots, f_N\} \quad (3)$$

f_i is real-valued and X represents the range of variation for all objectives.

4- Research findings

In this research, two groups were surveyed to advance the research process. The interviewees included a group of 20 traffic experts and 20 experienced drivers for the agility and reproducibility of the main research process, whose data were collected through oral interviews, and the second group was composed of experts who participated in validating the validity of the research. are given This group consisted of 150 people whose views were collected orally.

In order to determine the traffic variables in this research, firstly, traffic volume as the most important variable that affects the speed of the car, considering the intensity, based on that, we can identify other variables that affect it. Determining other variables affecting the variables obtained above in order to be aware of all the factors affecting the traffic volume as an important factor of car speed was also determined with other variables affecting the variables obtained from the traffic volume. After determining the variables, the relationships between the variables should be determined twice, the delays should be determined and the type of loops should be determined.

Using vensim software, the cause and effect model is shown in Figure 2.

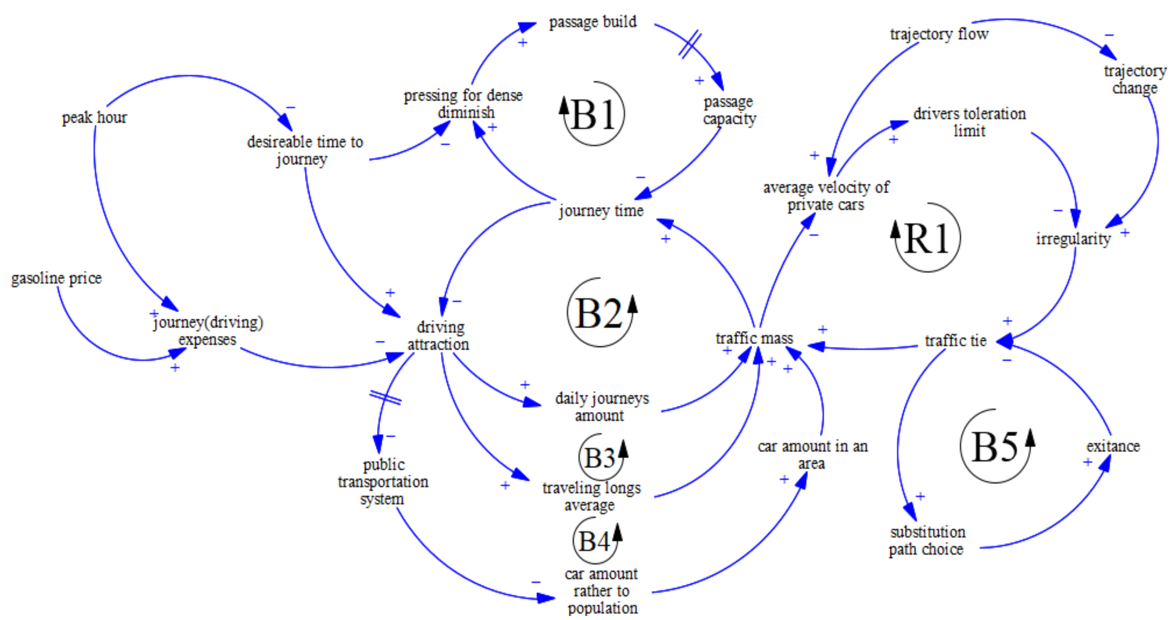

Figure 2: Cause-effect diagram of traffic variables in Vensim software environment

B_1 shows that the closer we get to the peak travel time, the pressure to reduce the congestion in the crossings increases, which makes city managers think about building new crossings and widening the old crossings, and because the construction and widening of new crossings takes time with delays and in the future, it will increase the capacity of the crossings. This leads to a reduction in traffic and a higher speed of the car, thus reducing the travel time. B_2 shows that the higher the volume of traffic, the longer the travel time, which leads to a decrease in the attractiveness of driving, and as the attractiveness of driving decreases, the number of trips also decreases and the volume of traffic decreases. B_3 shows that due to the reduction of attractiveness of driving in B_2, the average length of the trip is directly proportional to the attractiveness of driving. So, sometimes when the attractiveness of driving decreases, the length of travel by private car decreases and drivers try not to drive on long routes and look for alternative hours or alternative means of transportation, which leads to a decrease in traffic volume. B_4 shows that due to the decrease in the attractiveness of driving in the B_2, drivers turn to the public transport fleet, as a result, policy makers and city managers develop public transport, which will expand over time and in the future by reducing the attractiveness of driving the public transport fleet. It is found that the attractiveness of car ownership is decreasing and the number of cars per capita is decreasing. This important factor has also led to the reduction of cars in various areas, which results in a decrease in traffic volume. B_5 states that in the conditions of a traffic node where the volume of traffic cannot be moved, some drivers think of an alternative route and leave the exit of the crossing. This departure leads to a decrease in the number of cars in the crossing and the result is a decrease in traffic congestion.

In general, according to the graph above, the number of daily trips-the length of the trip-the amount of cars in a region has a direct effect on the volume of traffic, which makes the importance of reducing travel demand on the one hand and empowering public transportation on the other hand essential.

6-1Testing movement in the trajectory using game theory

The game matrix is shown in Table 1.

Table 1: Game matrix

S	B_1	B_2	B_3
A_1	15,10	۲۵*,۱۰	10,20
A_2	۱۵,۳۰+	۲۰,۲۰	20,40*
A_3	۱۰,۲۰	۲۰,۳۰+	۴۰*,۴۰+

The equilibrium point in this game is (A_3, B_3). B1 dominates B_2 and B_3. That is, the utility for B_2 and B_3 is less than the utility of B_1. And from column B_1, we find that none of B_1's preferences are marked. Also, A_1 is dominated by A_2 and A_3. That is, the utility for A2 and A_3 is at least as good as the utility of A_1. From lane A_1, we find that none of the utility of A_1 is marked. It means that strategies A_1 and B_1 are inferior by using zero-rank and are eliminated. By using rank-1, player A believes that player B will eliminate strategy B_1, so player A does not choose strategy A_2, which is a suitable response to B_1. Also, the first-ranked player B believes that A chooses the A_3 strategy, so it is better for him to choose the B_3 strategy, that is, the balance point of the combination of strategies (B_3 and A_3) is objectified on the condition that the first-ranked players obey.

As it is clear in this experiment, the feedback of the trend of the trajectory (cause) and change of the trajectory (disabled) is negative in this relationship. That is, as the cause, which here is the trend of the trajectory, increases, the effect, which is the change of the trajectory, decreases to a lesser extent than it would otherwise. In simpler words, in this experiment, the more the route became, the change in terms of saving from traffic and not changing the route, accidents, etc., decreased. And on the contrary, as the trend of the trajectory, which is the cause, decreased, the effect, which is the change of the trajectory, increased to a greater extent than otherwise. (only in terms of progress and passing through traffic, not changing the route, accidents, etc.) so the feedback between the progress of the route and the change of the route is negative. In this test, two drivers changed the lane to achieve higher speed, to get more speed from the crossing or to achieve higher speed.

The equilibrium point in this game (B_3 and A_3) was 40 km/h speed for both players, it shows that the drivers achieved a higher speed by changing the route. That is, with the increase of the cause, which is a straight lane, the effect, which is the speed, increases more than it would otherwise. If the trajectory is reduced, the effect, which is the speed of the car, will be reduced to a lesser extent than it would be otherwise. In simpler words, if the drivers saw that the side lane was moving and did not change the route, they would have moved at a lower speed, and they would have seen other cars pass by them. As the lane change increases, disorder will occur and it will lead to a traffic node that increases the volume of traffic and decreases the speed. According to what can be seen about the feedbacks, the trend of the route and the average speed of a private car have positive feedback, that is, with the increase of the trend of the route, the average speed of the cars also increases.

5- Conclusion

Today, both in developed countries and in developing countries, senior managers and policy makers of the transportation system are looking for solutions to deal with traffic in order to reduce the waste of time-energy resources and its environmental consequences. So far, a lot of work has been done in the countries of the world in order to reduce the demand for travel - optimizing and creating public transportation - proper distribution of trips - creating highways and increasing routes and access routes between travel areas, which can reduce the problem of traffic and its destructive effects. For this reason, it seems that the research done is very necessary.

This research includes two parts of dynamic modeling of traffic networks, which uses the experts' point of view to analyze the relationships between the variables of traffic creation in the environment of vensim modeling software and then the driving test on the inner city highway during peak traffic hours, the behavior of drivers in traffic conditions is analyzed with game theory tools. Drivers are players who try to pass the traffic network quickly in a non-cooperative manner. Therefore, they record their chosen routes and their maximum speed in that route to be analyzed. This game helps to be able to effectively and precisely understand the causes of traffic-planning in this area and to teach traffic behavior to drivers and traffic controllers.

The negative feedback between changing the trajectory and changing the trajectory means that the drivers intend to modify the selected trajectory to achieve a higher trajectory and speed. In the tested game, the Nash point is in the trajectory of the road, which shows that in traffic conditions, the road lane is faster than the fast lane and the middle lane; which was contrary to the drivers' idea. Considering the lower speed of the slow lane in traffic-free conditions and the presence of exits and entrances on the right side of the intersections, it is understood that drivers continue on the lane regardless of changing their route. By suddenly changing the route to exit the highway, they cause traffic. Due to the presence of exits and entrances next to the fast lane on the right side of the intersections and creating more traffic congestion in this area, drivers had the impression that the fast lane is faster, but The test carried out proved the opposite. Variables such as the reduction of travel demand, highway volume, gas prices, and a suitable public transportation system can have a direct effect on traffic. While the opinion of many drivers was that the traffic flow in the fast lane in traffic conditions Most of all, this experiment showed that the highest trend in traffic conditions occurred when the actors of the experiment were moving on lane 3 (slow).

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