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Investigating the Effects of Fuel Price on Inter-City Transportation Utilizing System Dynamics Approach and Simulation (Case Study: Inter-City Transport, Iran)

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Abstract:

Transportation system is known as a complex system composed of multiple variables and linear/non-linear feedback loops influenced by economic, geographical, social and environmental factors. Transport modeling is commonly proposed to evaluate and simulate the performance of system with or without inter-relations on transport system. In the present research work, system dynamics approach is utilized for modeling and simulating the intercity transportation in order to access the effects of fuel price on intercity roads traffic volume. The proposed model consists of internal interactions and relations on intercity transport system as well as simulation for validation. Sensitivity analysis has been done based on four scenarios on various fuel price increment rates of 5%, 15%, 20% and 25% in three different periods of five, ten and twenty years, known respectively as short, medium and long term periods. Simulation results revealed that during the above mentioned periods, commercial traffic on intercity roads are linearly grown up while the increasing rates of fuel prices has remarkable impacts on daily traveled vehicles over the intercity roads. Therefore, national authorities who are dealing with setting fuel prices should notice that policies on fuel prices have smooth impacts on intercity road traffic and should be carefully studied and investigated before taking decision.

Keywords:

Fuel Prices, Traffic Volume, Transportation, System Dynamic, Commercial Vehicles

1. Introduction

1.1. Transportation and Emission

Road transport system is a complex system involving multiple variables and non-linear feedback loops which are influenced by many attributes such as transport infrastructures, social, economic and environmental factors [1]. The surplus of cars and effects of environmental, economic and social aspects of urban life have become major global problems while continued population growth in urban areas and increasing the dependency on the use of cars will exacerbate this problem in the future [2]. On the other hand, the conventional methods of transportation are also heavily dependent on fossil fuels which should be saved for the next generations [3]. In developing countries, due to high speed of urbanization, in particular in Asia, environmental problems are getting to be much more serious and larger [4]. Nowadays, although more than half of the world's populations live in urban areas, but they are contributed more than 80% in greenhouse gas emissions related to human activity [5]. The relationship between traffic congestion and air pollution has been gained more attention in the discourse of sustainable development. In developing countries with low rate of using private cars, the main issue is the source of exacerbating the above mentioned problems [6] which is believed that transportation system is the major consumer of energy and emitter of greenhouse gases resulting from fossil fuel consumption and also one of the problematic sources to control the amount of pollutants. For example, more than 26% of the world's energy consumption was estimated to be in the transportation sector in 2004 and 23% of greenhouse emissions are known as the impacts of transport operations and activities [7].

1.2. Dynamics and Transportation

System dynamics approach, introduced by Jay Forrester in 1960, is one of developed methodologies for simulating systems to visualize and analyze complex and feedback-based systems [5]. System Dynamics is a methodology and mathematical modeling approach which is commonly utilized to explore the behavior of complex systems over a horizon time [2]. This approach is based on feedback control theory, equipped with computer simulation technology and quantitative and complicated research relating the economic and social system. In general, methods of System Dynamic approach include feedback loops, variables and equations which are understandable in this way. Feedback loop can be defined as a closed chain of cause and effect procedures which affects on each other internally and may be affected by other variables externally. Variables include (i) level variable, which accumulates flows during the time periods; (ii) flow variable that show processing flow during the time period; (iii) secondary variable that identifies the rate variables. These three variables are related to each other by means of integral, differential or other types of equations [1]. After proposing System Dynamics approach by Forrester, it was used in supply chain problems, industrial dynamics and urban dynamics [8]. System dynamics approach was also improved in the 1970s to describe the density and dynamics of complex systems. The main core of methodology of system dynamics is a great tool designed to identify the specific behavior of the system that provides a framework for researchers. Due to existing high complexity issues in road transportation systems and the wide range that they comprise, the usage of traditional approaches in order to simulate and analysis the system may not be enough appropriate. So, the System Dynamics approach is recommended to be used for analyzing and evaluation of inter-city transport system [9]. The designed framework helps researchers to understand theoretical analysis of systems sensitivity in response to structural changes so that researchers have been frequently used the approach for identifying the various aspects of transportation systems [10]. The first system dynamics model offered by Forrester in the field is urban modeling [4] in which system dynamics approach is commonly used in evaluating the performance of regional stability, assessing the relationship between transportation and land use and estimating the impact of industrial spaces on the environment [1]. System Dynamics is a systematic approach that is discussed as an effort to identify and study the issues related to the dynamic and complex problems relating long-standing policies in public and private spheres. This approach is based on the nonlinear dynamics theory and feedback control that is developed in the areas of math, physics and engineering. The main reason for using this approach to analyze and simulate road transportation systems is the complexity of the system in the real world [6].

1.3. Research scientific background

In the recent years, numerous studies and researches have been conducted in the areas of application of system dynamics approach in modeling, studying, analysis and simulation of transportation systems and their sub-sectors in order to predict the behavior of transport systems in the future. They are categorized in two parts of (i) urban transportation system (ii) suburban transportation system [2] utilized the system dynamics approach to evaluate and analyze the impact of adopted transportation policies in the central Iranian city of Isfahan and concluded that developing transit network can be one of the most important policies to achieve urban sustainability [11] by taking Shanghai city as a case study and based on system dynamics approach proposed a casual model of traffic congestion charging fee management (TCCF). Feng et al., focused on interrelations among main variables using simulation in the TCCF management model [5] and have studied urban energy consumption and CO_2 emissions in urban transport systems in Beijing, China. Using the system dynamics approach for modeling and simulating the Beijing municipal transportation system followed by investigating the results showed that all factors controlling the rate of population growth and economic development will be among the most important factors affecting CO_2missions in the coming years. Barisa et al., [12] presented a system dynamics model to formulate how fuel policy and initiatives and fuel consumption applied patterns influence the urban transportation systems in Latvia. The model has been simulated and concluded that the promotion and dissemination of the use of biodiesel fuels will be difficult in the future, and also, increased indirect taxes on vehicle fuel consumption can increase biodiesel fuel consumption in the city's public transportation. In another study, Vafa-arani et al., [4] proposed system dynamics model of urban transportation system in the metropolitan of the Iranian capital city of Tehran that consist two main sub-models of transportation and industry. Selected factors of urban air pollution in Tehran are simulated as the main factor and the behavior of transportation and industrial factors affecting air pollution in Tehran have been anticipated. Lewe et al., [8] modeled the city transport system with the help of system dynamics approach; this system dynamics model includes economic, social, mode of operation, the total demand factors for travelling and the capacity of transportation system. Their modeling was proposed as the form of conceptual model and can be simulated under certain scenarios associated with this system. Wang et al., [1] proposed a system dynamics model of urban transportation systems in the Chinese city of Dalian which includes seven major factors namely: population, economics, the number of vehicles, environment, travelling demand, supply and traffic congestion. The model was used to simulate the transport of Dalian and concluded that the balance between population, transport, economy and environment will be a great problem in the future. Wen & Bai [10] constructed a system dynamics model for simulating the impact of different strategies on urban traffic’s energy consumption and carbon emissions. Based on a case study in Beijing, the model includes three subsystems: urban traffic, population and economy, and energy consumption and carbon emissions. Ercan et al., [3] have attempted for modeling the America's public transport system using system dynamic approach and have analyzed the potential to reduce carbon emissions using the simulation process under different modes. Han & Hayashi [7] have proposed a system dynamics model of intercity passenger transportation system in Shanghai, China, to reduce CO_2 emissions. They concluded that development of road networks (highway) and taxation of vehicles, is the most important and effective policy in reducing CO_2 emissions. Ercan et al., [13] simulated the United States urban passenger system that dependents on car modes. They found how public transportation in the United States as the existing urban structures should be the main causes of excessive trip generation and increasing average trip lengths. Lei et al., [14] have also proposed a model as a system dynamics model of low-carbon urban transportation in Shanghai, China. After simulating the system under different scenarios, they achieved the conclusion that the amount of air pollutants will be increased over the next five years, and the increase in population and number of vehicles are among emissions the most important growth factors. Menezes et al., [15] used system dynamics approach to modeling and simulating low-carbon development strategies in the transport sector of Sao Paolo city which is one of the largest cities in the world. They focused on analyzing selected policies such: diminution of frequency and distance of vehicles trips, improvement of public transport and technological issues, from improvement of fuel efficiency of all transport modes to replacement of fossil fuels by bio-fuels. Mcmahon [9] developed a theoretical dynamical system model of an intelligent urban transportation system. Using simulation tools, they have analyzed the effects of the smartness of hardware and software bases of urban transportation system on driving quality and sustainability of the system. He & Chen [16] mapped the casual relationships of the Wuhan city traffic system, using the principles and method of the system dynamics in order to implement the simulation model for governing the urban traffic congestion. They comprehensively analyzed the causal relationship between the variables that impact of urban traffic congestion.

Manataki & Zografos [17] have proposed a system dynamics model from Athens, Greece airport to analyze and evaluate the performance of the airport terminals using the modeling and simulation of system dynamics approach. Miang & Love [18] have discussed about methodological application of the system dynamics approach in evaluating road transportation traffic safety policy. In this regard, two models of system dynamics have been developed to describe how traffic safety policies can be improved in two macro and micro levels. Huirong & Xiaoning [19] have also analyzed the performance of Integrated Transportation system using system dynamics approach in China; and after simulating the system based on experimental data, they came to the conclusion that the resource allocation plays the most important role in operational activities of the system. Regarding to the relationship between the road traffic congestion and air pollution in the city of Accra-Ghana, Pasaoglu et al., [20] provided a system dynamics model of EU road transport sector. Their simulation model was running up to 2050 using five different scenarios such as: oil prices, GDP growth, learning rates, purchase subsidies and EU emission targets. The findings show that the simulated model is able to give strategic insights to authorities, manufacturers and infrastructure providers in relation to medium and long-term procedures in the EU road transport sector, Armah et al., [6] have proposed a system dynamics model of the road transportation system. Simulating their proposed model concluded that the main measures to improve air pollution in future include: the development of public transportation, road network development and management of travel demand.

1.4. Vision

In the Islamic republic of Iran, many countermeasures have been implemented to prevent the growth of traffic congestion on roads (in particular urban areas) and to also reduce the environmental pollution caused by traffic and traffic congestion. One of the most remarkable policies over the recent years is to raise the fuel prices for both gasoil and petrol. Since, many studies have been conducted to investigate the relationship between fuel prices and traffic volume; it seems that they should be investigated by studying inter-relations over the contributed factors on traffic volumes. Therefore, using system dynamics modeling has been utilized to investigate road transportation and various scenarios of future increment rates in fuel prices to illustrate the impacts of increasing fuel prices the road traffic volumes in this research work. Following all of the above mentioned, the main reasons of conducting this research work are briefly: 1) Investigating the Iran's road transportation system modeling using system dynamics approach, 2) Simulating the effects of fuel price policies on road traffic congestion in Iran and 3) Examining the relationship between fuel prices and the density of traffic on the roads.

2. Developing System Dynamics Model

A system dynamic model consists of three main stages of modeling cause and effects relations, modeling feedback loops, and drawing system flowchart which are discussed in this section for developing rural transport model and traffic volumes over the system.

2.1. Cause and Effect Model

As said before, road transportation system is a complex system affected by many factors with the nature of economic, transportation and social [1]. The conceptual cause and effect model provided for this complex system consists of sixteen key factors expressed based on nature as follow:

(i) Economic factors: the economy (GDP), the price of gasoline, price of petrol, the price of CNG, taxi price level and bus fare level.

(ii) Transportation factors: traffic density, the total number of vehicles, the number of personal vehicles, the number of taxis, buses, the number of cargo vehicles, travel demand and travel supply.

(iii) Social factors: population, environment. Cause and effect model shows the relationships between different variables and factors of road transportation system and also shows the type of this relationship.

In this structure, sub-models of population, economy and count of vehicles play fundamental roles, and, together with the sub-models of prices of different fuels, contribute largely into the traffic density and hence to the environment variable.

The traffic density sub-model is developed as a result of the interaction between transportation supply and demand sub-models and its feedback is imposed into the economy model. Environment and fuel prices sub-models are among the factors limiting the development of road transportation system, i.e. road traffic density,

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thereby affecting economy and population sub-models. Cause and effect model of road transportation system is based on system dynamics approach showed in Figure 1.

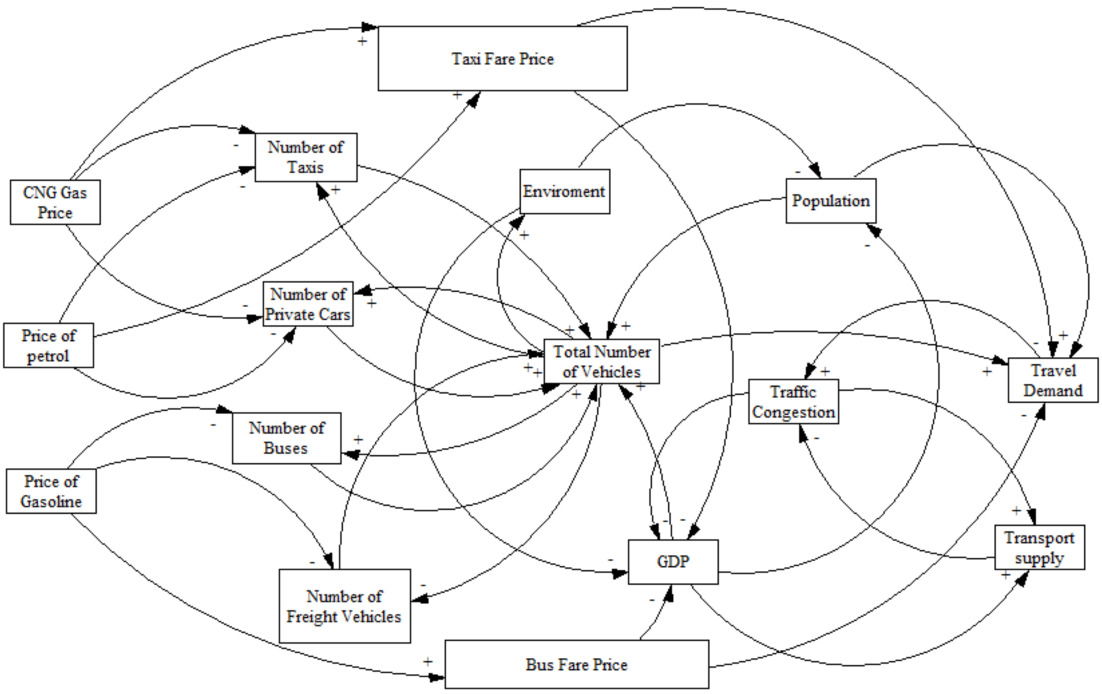

Figure 1. *Cause and Effect Model.*

2.2. Model Feedback Loops

The most important model feedback loops are defined as follows:

(i) Economic development (GDP) is generally associated with a growth in demand for mobility and personal car. A growth in vehicle ownership increases environmental (air) contamination which in turn negatively impacts the rate and quality of the economic development. Respective negative feedback loop is depicted in Figure 2.

(ii) Economic development results in an increment of the number of vehicles, and this in turn enhances the demand for trips. This increased demand for trip ends up with increased road traffic density which in turn erodes the motivations toward undertaking economic activities, ending up with reduced GDP. Respective negative feedback loop is demonstrated in Figure 3.

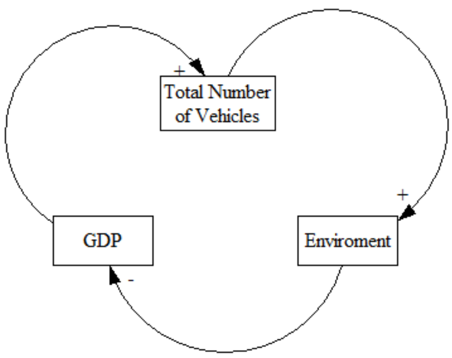

Figure 2. *Negative Feedback Loop of GDP.*

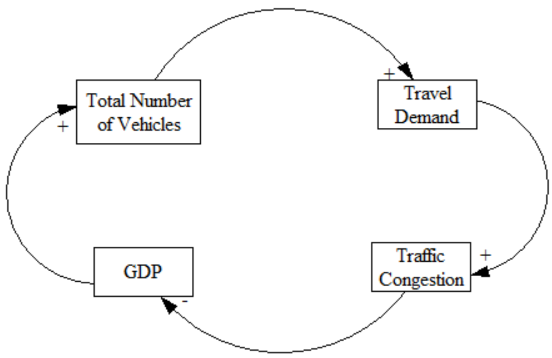

Figure 3. *Negative Feedback Loop of Traffic Congestion.*

Due to rapid economic development, total number of vehicles increases and this leads to higher environmental (air) contamination levels. However, such an unfavorable environmental condition deteriorates attractiveness of the respective settlements and boosts the migration from urban cores. This migration from urban areas will boost the traffic density within road transportation system, thereby impacting the economic development negatively. Respective positive feedback loop is demonstrated in Figure 4.

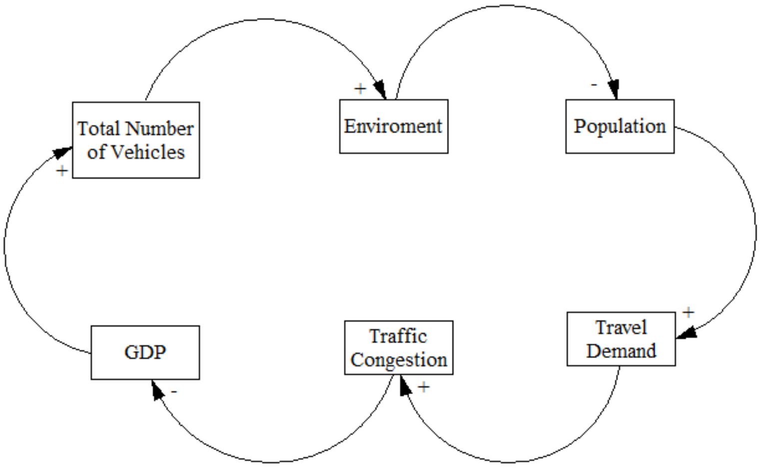

Figure 4. *Positive Feedback Loop of Total Number of Vehicles.*

In addition to the above-mentioned feedback loops, other feedback loops of small sizes exist within the presented dynamic system, referred to as closed feedback loops; these tend to affect the model behavior along the primary feedback loops.

2.3. Road Transportation System Flowchart

Cause-and-effect diagram of the dynamic system model is now considered as the base of the present study. The proposed model not only provides a theoretical basis for understanding the transportation system structure, but also describes the scope and boundaries of this study. Cause- and-effect relationships and feedback loops of the model allow for observing interactions between sub-models and their effect on overall behavior of the system (traffic density) by defining the relationships among them throughout time.

Therefore, the effect of changes in prices of different fuels on traffic density is not a direct one, but is rather transferred via and in proportion to the cause-and-effect relationships among the sub-models. Feedback loops play the most important role in dynamic system models, so that they always contribute to either the growth or weakening of the system throughout time. A change in fuel prices begins with imposing a positive effect on general level of fares, although it is negatively related to the count of vehicles. Such an increase in fuel price affects per capita income negatively via the increase in fares. On the other hand, this will reduce the demand for vehicles purchase. Economy sub-model is negatively affected by other components of the transportation system, such as environment, giving the respective feedback in the form of total number of vehicles sub-model which ends up with a negative feedback loop.

On the other hand, there are cause-and-effect relationships between other variables including environment, population, economy, and trip supply and demand. Resultant effect of these relationships contributed to the main research variable, i.e. traffic

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density. Therefore, it is observed that, in complicated systems which are modeled via a dynamic system approach, effect of a factor on another factor within the system is not direct, but rather depends on the relations among different sub-models and structures of feedback loops. In order to present a mathematical definition for the relations between different sub-models, one requires the following data: time, types of model variables, and dynamic system model simulation, so as to plot the model flow diagram.

Based on the proposed cause-effect model and relationships and feedback loops between these factors and road transport system, the road transportation system flowchart can be proposed according to the structural characteristics of the model (Wang, Lu and Peng, 2008). At this point, the type of variables has been identified and the relevant equations based on the feedback structure and cause-effect loops are established. Any of the factors and variables has been displayed depending on the nature and type (level variable, flow variable and secondary variable).

Under the models, the secondary and rate variable associated with each of the main factors have been identified and placed in the flowchart. After this step, the modeled system can be simulated under the considered scenarios in the given time periods and changes in behavior of the system is studied and assessed. The flowchart is shown in Figure 5.

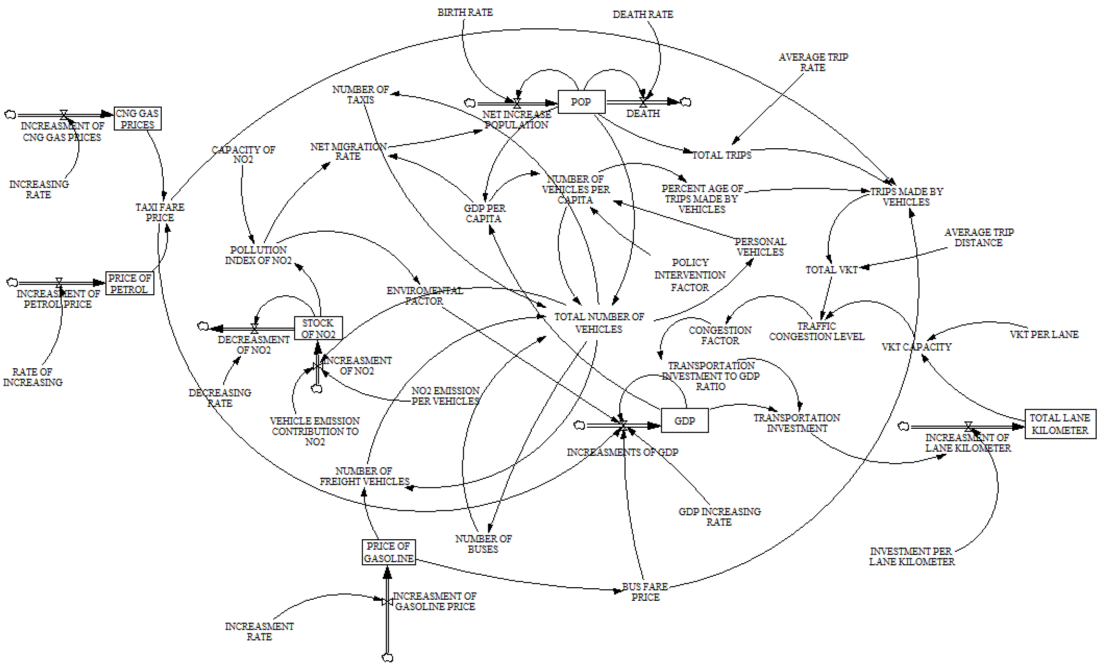

Figure 5. *Flowchart of the Model.*

3. Simulating the Road Transportation System

Since the system dynamics model is complex consisting of many variables, the amount of variables and coefficients used in the model to simulate is important. To estimate the values of parameters and variables of the system dynamics model, three methods are usually implemented including statistical data, credible reports and correlation analysis.

3.1. Model Validation

In order to validate the proposed system dynamics model, economic, transportation and social data have been used based on Iranian transport system available data in 2009 and simulated up to 6 years (until 2014). Though this is not sufficient to validate the proposed model; however, given the lack of reliable data and its lack of accessibility, the pre-2009 data on comprehensive transportation have been used for simulation. GDP simulation output values, population and number of vehicles in 2014, have been compared to reported data from the Central Bank of Iran, Iranian Center of Statistics and the Iranian road maintenance and transport organization which is responsible to collect tool and income on road transportation and results shown in Table 1. Simulation errors, almost makes sense and has a high error rate of GDP value is likely due to the instability of foreign exchange system as well as unforeseen economic sanctions in the recent years.

Table 1. *Validation Results: Model's Outputs Comparing to Actual.*

Index	Model Output	Actual (Real)	Error
Number of vehicles	16,500,000	17,000,000	-3.03%
Population (Person)	76,950,000	77,800,000	-1.17%
GDP (Billion-Rial*)	2,831,596	2,031,596	+28.2%

* *Iranian currency*

3.2. Simulation Scenarios

In order to simulate the proposed system dynamics models on intercity road transportation system, it is necessary to define different scenarios for simulating models. It should be done for assessing the impact of changes in fuel prices on road traffic density. Variables and parameters of the proposed model have been initialized and made ready to run the simulation stage using the well-known software of VENSIM PLE using data available in 2014 (1393 in Lunar calendar) as the base year. Simulation steps are utilized in all scenarios for the base year. Simulation results have been aggregated annually. Pre-defined simulation scenarios have two major characteristics of time and change rate of fuel price which are the main points of investigating. Simulation scenarios have been tabulated in Table 2 in which all years have three scenarios of increment rate on fuel price. Since, all parameters have been calculated annually, simulation step has been set as a year.

Table 2. *Simulation Scenarios (Simulation step: One year).*

Scenarios	Simulation Horizon (Year)	Increment Rate for Fuel Price
Short-term	Five	5, 15, 20 and 25 Percent
Mid-term	Ten	5, 15, 20 and 25 Percent
Long-term	Twenty	5, 15, 20 and 25 Percent

3.2.1. Scenario I (Short-term changes)

In this case, the objective is to consider the effect of changes in fuel price on road traffic density across the country during a five-year period. This will indicate the short-term changes in the volume of traffic along Iranian roads, as compared to the reference year. Simulation horizon length is 5 years with incremental steps of 1 year. For this purpose, three cases of changes in fuel prices in the country are considered:

(i) 5% increase in fuel prices (gasoline, gasoil, and CNG).

(ii) 15% increase in fuel prices (gasoline, gasoil, and CNG).

(iii) 20% increase in fuel prices (gasoline, gasoil, and CNG).

(iv) 25% increase in fuel prices (gasoline, gasoil, and CNG).

3.2.2. Scenario II (Mid-term changes)

In the second scenario, we aimed at investigating the effect of changes in fuel price on road traffic density across the country during a ten-year period (mid-term), as compared to the reference year. In this case, simulation horizon length is 10 years with identical annual increment. Similar to the previous scenario, 5%, 15%, 20%, and 25% increases in fuel prices (gasoline, gasoil, and CNG), as compared to the reference year, were considered in this scenario, with each of them applied separately to simulate the ten-year period.

3.2.3. Scenario III (Long-term changes)

In the two previous sections, scenarios for investigating the effects of changes in fuel prices on road traffic density in five- and ten-year periods (short- and mid-term, respectively) were presented, considering fixed rates of increase per year (5%, 15%, 20%, and 25%) for the simulations. In order to further investigate the effect of long-term changes, a 20-year period was simulated with 1-year step lengths. Similar to the previous scenarios, 5%, 15%, 20%, and 25% increases in fuel prices compared to the reference year were considered in this scenario, with a twenty-year simulation horizon length. Table 2 reports the simulation characteristics under different scenarios.

3.3. Analytical procedures on Road Transportation System

Using the simulation software of VENSIM PLE, road transportation system dynamics model has been simulated under for pre-defined scenarios in four different increment rates and results have been outlined and tabulated in Table 3.

Table 3. *Estimated Daily Traffic on Intercity Road Network (Million Commercial Vehicles).*

Scenario			Horizon (Year)	Annual increment rate for fuel price			
				5%	15%	20%	25%
Long-Term	Medium-Term	Short-Term	1	17.85	17.83	17.83	17.84
			2	18.73	18.70	18.71	17.16
			3	19.66	19.61	19.62	19.64
			4	20.16	20.57	20.59	20.60
			5	21.67	21.57	21.59	21.62
			6	22.75	22.62	22.65	22.68
			7	22.38	23.72	23.76	23.01
			8	25.01	24.88	24.93	24.97
			9	26.32	26.09	26.15	26.20
			10	27.63	27.36	27.43	27.49
			11	29.00	28.70	28.77	28.85
			12	30.44	30.10	30.18	30.27
			13	31.96	31.56	31.36	31.76
			14	33.55	33.10	33.21	33.32
			15	35.22	34.72	34.84	34.97
			16	36.97	36.41	36.55	36.69
			17	38.81	38.18	38.33	38.49
			18	40.74	40.04	40.22	40.40
			19	42.76	42.00	42.19	42.38
			20	44.89	44.40	44.25	44.47

The first scenario: Outputs of simulating for the first scenario have been tabulated in Table 3 in rows 1 to 5. As observed, results lead readers to find out that there is no significant difference between the rates of travelling vehicles for different increment rates of fuel prices.

The second scenario: Outputs for the second scenario have been shown in Table 3 in rows 1 to 10 all defined increment rates of fuel prices.

The third scenario: Outputs the third scenario have been also tabulated in Table 3 in rows 1 to 20 for all defined increment rates of fuel prices.

In order to make better understanding on the rate of traffic growth, Figure 6 has been depicted according to the annual fuel price increment rate of 20%. As shown, a smooth increasing rate would be happened over the next years. According to what observed in case study, it seems that commercial vehicles' traffic growth is mainly affected by population not fuel price because intercity transport is not a luxury service.

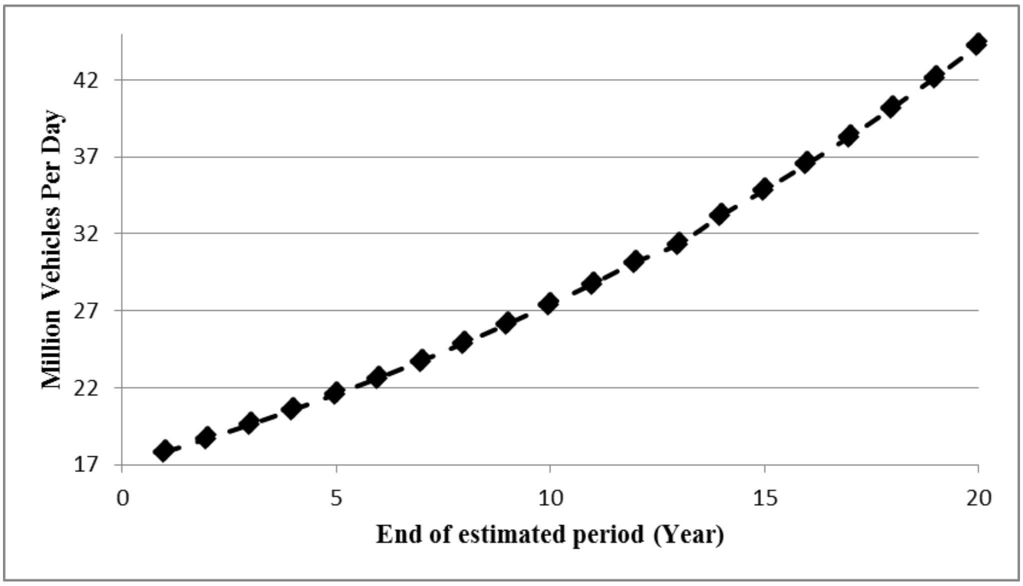

Figure 6. *Estimated Daily Traffic of Commercial Vehicles for Fuel Increment Rate of 20%.*

4. Conclusions

According to the results of simulation applied on the proposed system dynamics model of road transportation system under the applied scenarios, it can be concluded that according to population, positive economic growth and increased annual investment in development of road transportation infrastructure by the government of the country, the changes in the fuel price variable under fuel policies cannot be used to reduce the amount of movement of vehicles on the road of the country. It can be seen that in case that it increases as mean and average fuel prices in the country, with an annual rate of 5%, 15% , 20% and 25% in the short term, medium term and long-term, it has a significant impact on the amount of cars in traffic on country's roads and, consequently, the volume of road traffic. Although with the increase in the fuel prices rate, the number of vehicles on the anticipated time periods will be reduced, however this amount is not significant according to extensive road network and an annual population growth of the country. The current daily traffic congestion on the roads and the daily traffic congestion at the end of the simulation periods have been shown in Table 4 based on the fuel annual price increase rates.

Table 4. *Estimated Daily Traffic on Intercity Roads (Vehicle).*

Current Daily Traffic	Increment Rate for Fuel Price	End of 5 Years Period	End of 10 Years Period	End of 20 Years Period
17,000,000	5%	21,671,000	27,625,400	44,891,800
	15%	21,619,400	27,494,000	44,466,000
	20%	21,593,700	27,428,600	44,254,600
	25%	21,696,100	27,363,300	44,044,200

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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