An Appraisal of Sustainable Urban Transportation: Application of a System Dynamics Model

Amir Abbas Rassafi[1] , Mahdi Ostadi Jafari[2] , Hassan Javanshir[3]

Received: 02.08.2013 Accepted: 21.09.2014

Abstract

Increasing pressures caused by negative consequences of transportation and traffic problems in major cities, have resulted many attempts towards improvement of planning and management of transportation systems, according to sustainability objectives. In this paper, a comprehensive model is developed using a system dynamics approach to evaluate sustainable urban transportation. This model includes social, economical, environmental, and urban transportation variables. Then, the validation of the model according to actual data for years 1994 to 2009 of City of Mashhad are performed. The base year for simulation was 2009 and the horizon year was 2044. This stage is very important because all of the analyses and decisions made in the following steps will be based on the calibrated model. The sensitivity analysis of the parameters of the model showed that the selected variables have considerable influences on urban transportation sustainability. The proposed model can be used to find the optimal strategy for sustainable urban transportation.

Keywords: Sustainability, urban transportation, system dynamics, simulation

Corresponding Author E-mail address: mahdi.ostadijafari@yahoo.com

1- Associate Professor, Department of Civil Engineering, Imam Khomeini International University, Qazvin, Iran.

2- MSc. Grad, Department of Civil Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran.

3- Assistant Professor, Department of Industrial Engineering, Islamic Azad University, South Tehran Branch, Iran.

1. Introduction

Currently, considering sustainable development issues in all decisions at different levels is one of the most fundamental needs of the managers and planners. The growing concern regarding unleashed use of nonrenewable resources as well as environmental and social consequences of development especially in transportation sector, which is one of the major sources of different kinds of pollution, was the genesis of paying attention to the concept of sustainable development. Transportation has a remarkable role in sustainability issues in all scopes and levels of decision-making. Transportation impacts on and, at the same time, is affected by development and this makes the decision-makers pay more attention to the transportation as the most important element in sustainable development. Emerging problems like increasing consumption of fossil fuels, air pollution, water and soil contamination, unequal use of transportation systems, exposure to noise and air pollution, and also increase in accidents have imposed severe economical, social, and environmental damages to the society.

There are numerous works devoted to the study of sustainability and transportation. However, a small number of them analyze sustainability quantitatively. Sustainability in the current paper is a goal that is achieved by concurrent paying attention to social, environmental, as well as economical aspects of the system under study. The current study attempts to model sustainable transportation using a system dynamics approach. System dynamics models consider the causal relations feedbacks of variables and apply delay or unequal effects of parameters in a better way than static models. These are more suitable methods for long-term evaluations in future years.

In the current paper, the transportation, social, environmental, and economical indicators and their mutual relations are considered and modeled. Then, given the available data, the calibrated model is validated. The data for calibration and validation was gathered from Mashhad (a major city located at the north east of Iran) in different years.

The paper is organized as follows: First, the concept of sustainable transportation and its components is discussed and system dynamics model is introduced. Then, the methodology is presented and the transportation, social, environmental, and economical subsections of the proposed model is developed. Afterwards, the model validation as well as sensitivity to its components is discussed. After the concluding remarks, references are presented.

2. Concept and Components of Sustainable Transportation

The concept of sustainable transportation is derived from that of sustainable development. Understanding aspects and objectives of sustainable transportation requires indentifying the role of transportation in development of urban systems. There are several definitions

Table 1. Selected indicators to evaluate sustainability level of SUT model

Aspect	No	Indicator	Unit	sign
Economical	1	value of time lost due to delayed passengers vehicles	IRR	-
	2	Ratio of environmental loss to annual income of transportation	-	-
	3	Annual uncompensated loss of transportation	IRR	-
	1	Equity in exposure of citizens to air pollution in regions	Kg / person	-
	2	Availability of public transportation in regions	Minute	+
	3	Ratio of mortal accidents to total trips by motor vehicles	Accident / trip	-
	4	Ratio of injury accidents to total trips by motor vehicles	Accident / trip	-
	5	Ratio of non-injury accidents to total trips by motor vehicles	Accident/trip	-
	6	Ratio of total accidents towards total trips by motor vehicles	Accident/trip	-
	7	Portion of trips using bicycle	%	+
	8	Portion of trips by walking	%	+
Environmental	1	Portion of noise pollution in urban regions	db	-
	2	Annual gasoline consumption towards total gasoline vehicles	Liter/vehicle	-
	3	Annual gas consumption towards total gas vehicles	Liter/vehicle	-
	4	Annual NO_X production towards region of the region	Kg/m^2	-
	5	Annual HC production towards region of the region	Kg/m^2	-
	6	Annual CO production towards region of the region	Kg/m^2	-
Transportation	1	Moved distance of the vehicles	Vehicle km	-
	2	Portion of public transportation towards traffic of private	%	+
	3	Number of non-marginal parking lots towards private transportation	Number	+
	4	Average speed of vehicles	Km/hr	+
	5	Average traffic congestion (v/c)	-	-
	6	Average time of trip	Minute	-
	7	Daily moved passengers	Person	+
	8	Portion of trips by bus in daily trips	%	+
	9	Portion of trips by private vehicles in daily trips	%	-
	10	Portion of trips by taxi in daily trips	%	+
	11	Portion of trips by bicycle in daily trips	%	-

for sustainable development and sustainable transportation [Rassafi et al., 2006; Rassafi and Vaziri, 2007; Zhang and Wei, 2013]; however their core idea relies on the definition of World Commission on Environment and Development in the Brundtland Report [World Commission on Environment and Development, 1987]:

“Sustainable development is development that meets the needs of present generation without compromising the ability of future generations to meet their own needs”,

As well as that of World Bank [Development Committee., 1987]:

“Economic growth, the alleviation of poverty and sound environmental management are in many cases mutually consistent objectives”.

The first definition implies that sustainability is a long-term objective that involves more than one generation, and the second one points to three dimensions of economic, social, and environmental for sustainable development.

The current study defines sustainable transportation as an optimal strategy for development in transportation systems while paying attention to social and environmental aspects of society. Furthermore, due to the importance of measurement techniques in sustainability appraisal studies [Rassafi and Vaziri, 2005], a great emphasis has been devoted to them. Therefore, 28 indicators have been selected and have been introduced to evaluate sustainability level of the sustainable urban transportation (SUT) model. This selection is based on availability of the information, possibility of measurement, and also the accepted definition for sustainable transportation. As Table 1 shows, the number of economical, social, environmental, and transportation indicators is 3, 8, 6, and 11 respectively. It is notable that in order to meet sustainability objectives, the combination of indicators are deemed to be evaluated, and synchronized improvement of them is considered in the model. In the last column titled “sign”, a positive sign for each variable represents the affirmative influence of that variable on sustainability and vice versa.

2.1 Economy and Transportation

The share of transportation sector in GDP (Gross Domestic Product) is about 10% in Iran in 2004 [Khalatbary and Atwan, 2008]. Formation of gross capital stock in transportation sector in constant price of 1997 has been grown up 16.2 times in period of 1959 – 2003, that is about 6.2% per year [Khalatbary and Atwan, 2008]. Transportation plays a key role in economical development from several points of view. On the one hand transportation has a direct effect on the economy in terms of value added. On the other hand, it connects economic centers that are inevitably located far from each other. This characteristic cannot be directly measured but it is noticeable that without transportation no economic firm can survive. Furthermore, transportation produces externalities, including the costs such as delays caused by congestion, environmental costs and accidents.

2.2 Society and Transportation

Man builds vehicle and roads and is the main user of transportation. Moreover, variety and extensiveness of transportation systems have affected the social life of the people. Population, culture, equity, health, safety and accessibility are effective social issues involved in sustainable transportation. Transportation and society have mutual interactions: transportation brings welfare, accessibility, and also noise, pollution, delay and accidents to the society, and in turn, society’s habits and lifestyle affects transportation [Schade and Rothengatter, 1999]. Cultural issues including level of participation, and compatibility with new policies like using non-motorized transportation, etc…. are also important. Equity has been one of the major concerns of transportation decision-makers too. Providing the same services for disabled or elderly as the same as others, as well as availability of public transportation to underprivileged are of great importance in equity issues [Habibian and Ostadi Jafari, 2013].

2.3. Environment and Transportation

Despite of its remarkable benefits, transportation has negative consequences and irreversible losses to the society and environment. The main impacts of transportation on environment are basically categorized into two major groups: consuming non-renewable resources, and environmental pollution. In energy sector, transportation has consumed about 30.4 % of total energy consumption of Iran in 2003, which shows 5.7% increase comparing with the previous year [Deputy of Energy Affairs, 2003]. Among oil products in 2004, 21986.3 billion liters gas and 15802.4 billion liters gasoline have been used by transportation sector, which is the most consumption rate in whole country [Deputy of Energy Affairs, 2003].

3. System Dynamics Model

System dynamics models have been introduced before 1960s, when Forrester and Sloan tried to present a management method in a long term, and finally they succeeded to publish a report called Industrial Dynamics in 1961 [ASTRA, 1999]. Then this idea was developed and it is widely used in several studies from different disciplines [ASTRA, 1999]. System is composed of elements and components which form a unique entity and has a specific and common objective [ASTRA, 1999]. In a systemic viewpoint, systems can be either open or closed. Closed or Feedback Systems do not have any connection with the elements outside the system's boundary and the behavior of the system is only affected by its behavior in previous time steps, means that it consists of a loop or loops relating the results of previous actions to next action.

Elements of causal loops include independent variables (cause), dependent variables (effect) and arrows showing the relation between cause and effect [Bakhshandeh et al., 2013]. By forming diagrams of causal loop, a concept called polarity of the loop, arises [Wang et al. 2008]. When the loop has a feedback contrary to its origin, the loop is negative, and when the loop has a feedback which amplifies its origin, the loop is called positive. As an example, Figure 1 shows two kinds of feedback loops. The left loop in Figure 1, a positive one, states that increase in population, amplifies the land development, and the latter has a positive impact on economic activities of the city which in turn causes population growth. The right loop shows that population growth increases the number of vehicles in urban regions. The emissions of these vehicles gradually result in a long-term accumulation of polluted air and thus reduce urban air quality, which has a negative impact on population [Chen et al., 2006].

Variables and parameters of a system dynamics model are divided into 5 categories: state, rate, constant, auxiliary, and exogenous [Sterman, 2000]. State variable represents the value of variable level at a particular time.

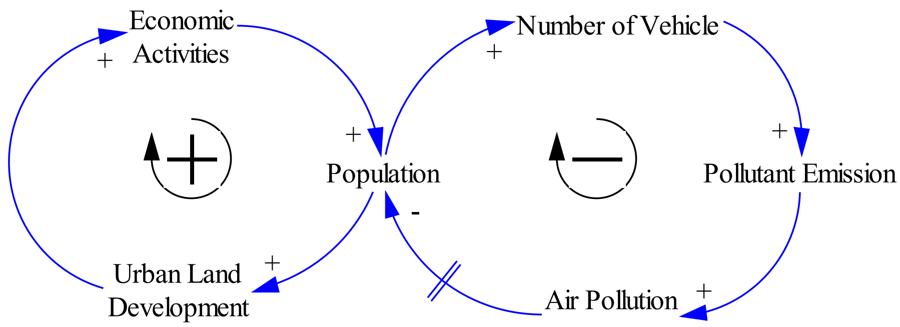

Figure 1. Positive and Negative Feedback loops [(Chen et al., 2006]

The increases or decreases of the state variables are determined by rate variables. Constants will remain unchanged during the time and exogenous variable is independent and at not affected by variable inside the model. Auxiliary variables are simply computed by the combination of aforesaid variables. The current values of state variable are determined according to increase or decrease of changes in previous period. This is shown in equation (1) [ASTRA, 1999]:

$$Z_t = Z_{t-\tau} + (IZ_\tau - DZ_\tau)(DT) \quad (1)$$

Where:

Z_t: The current value of state variable Z at time t (unit)

$Z_{t-\tau}$: The value of state variable Z at time t-τ (unit)

IZ_t : Rate of in flow (unit/time)

DZ_t : Rate of out flow (unit/time)

4. Methodology

This section describes the proposed model regarding the above explanations. Firstly, preparation stages of system dynamics model and its usage to form the model are presented, and then, sub-models of each section are described.

4.1 Preparation of System Dynamics Model

Generally, preparation of system dynamics models includes three stages: creating conceptual model, drawing flow diagram, and developing system dynamics model.

4.1.1 Conceptual Model of Sustainable Urban Transportation

Causal diagrams have been used to prepare conceptual model of SUT to show the relation between variables of model. These are shown in Figures 2, 3, 4 and 5, and presenting economical, social, environmental and transportation cause-and-effect relations among different variables, respectively. For example, from conceptual loops of Figure 2, fuel consumption of vehicles causes pollution production. Producing air pollution causes creation and increase in environmental costs which will affect financial sources of transportation in economical section. In order to decrease costs and negative consequences of transportation, pricing policies can affect usage of public transportation.

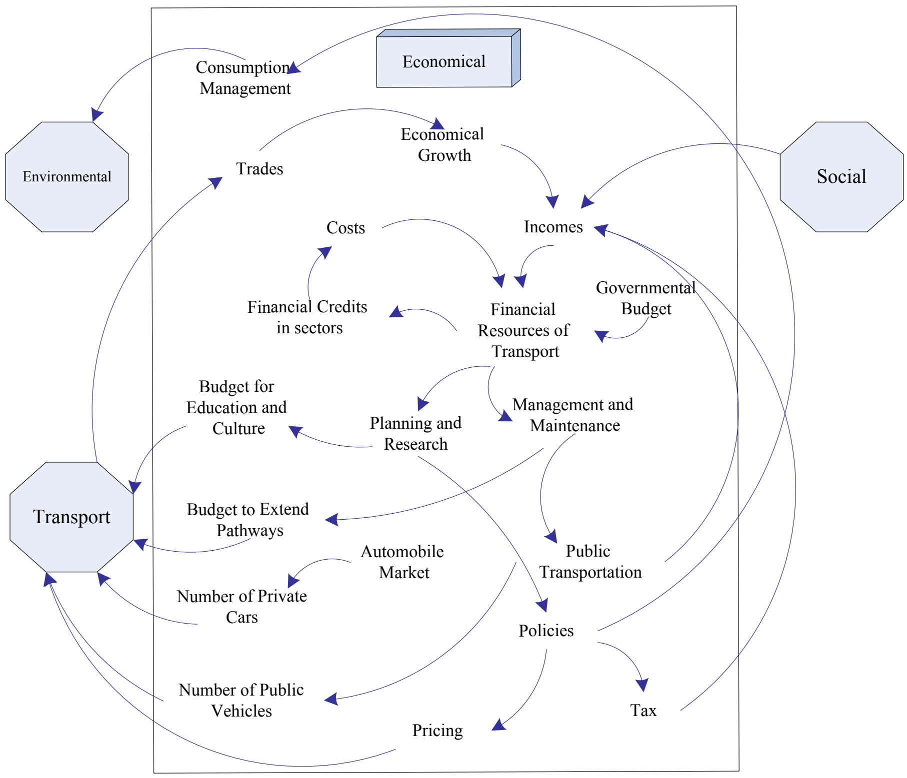

Figure 2. Conceptual economical sub-model of SUT

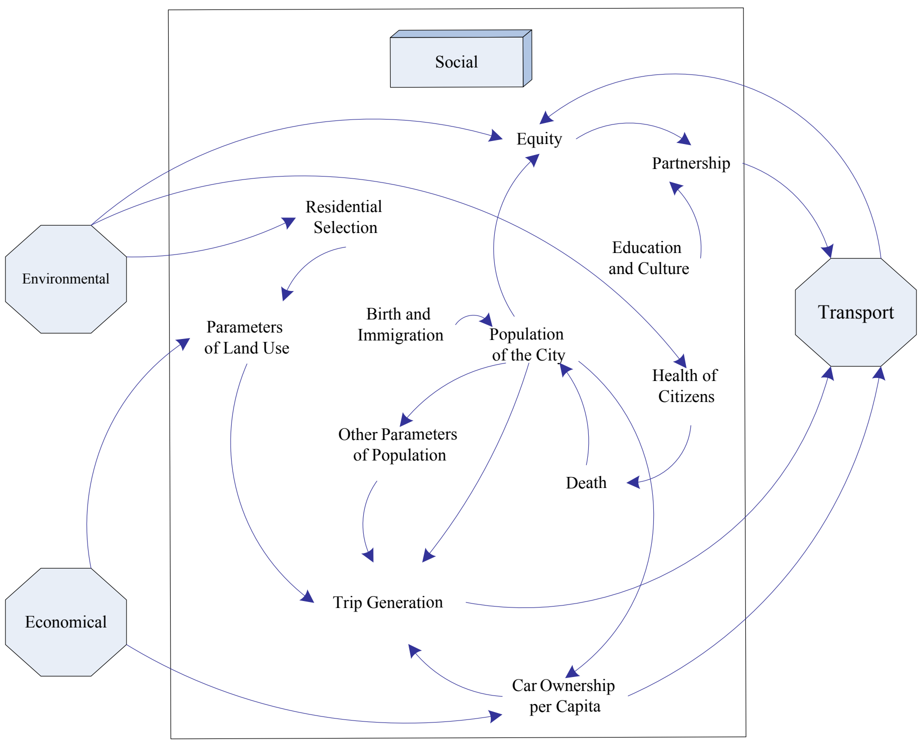

Figure 3. Conceptual social sub-model of SUT

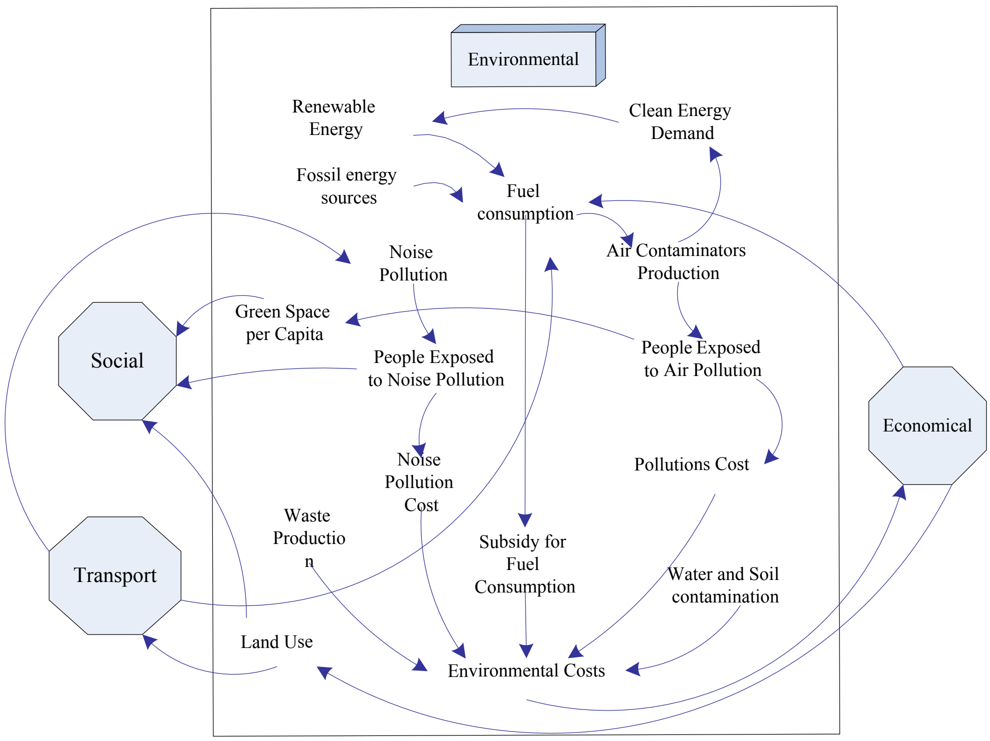

Figure 4. Conceptual environmental sub-model of SUT

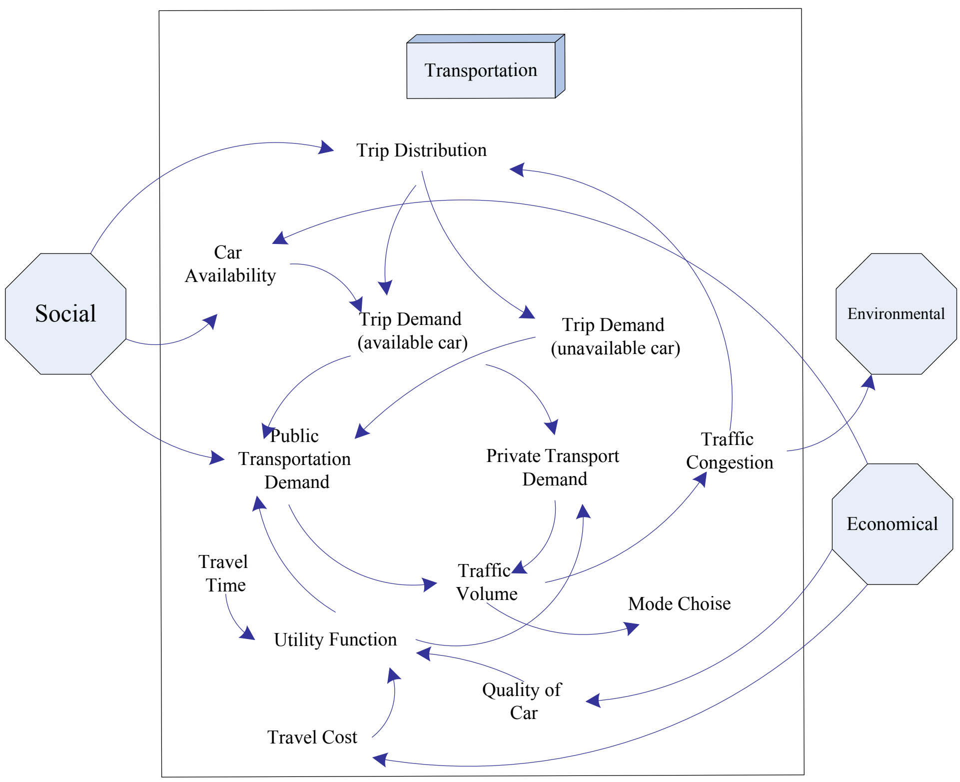

Figure 5. Conceptual transportation sub-model of SUT

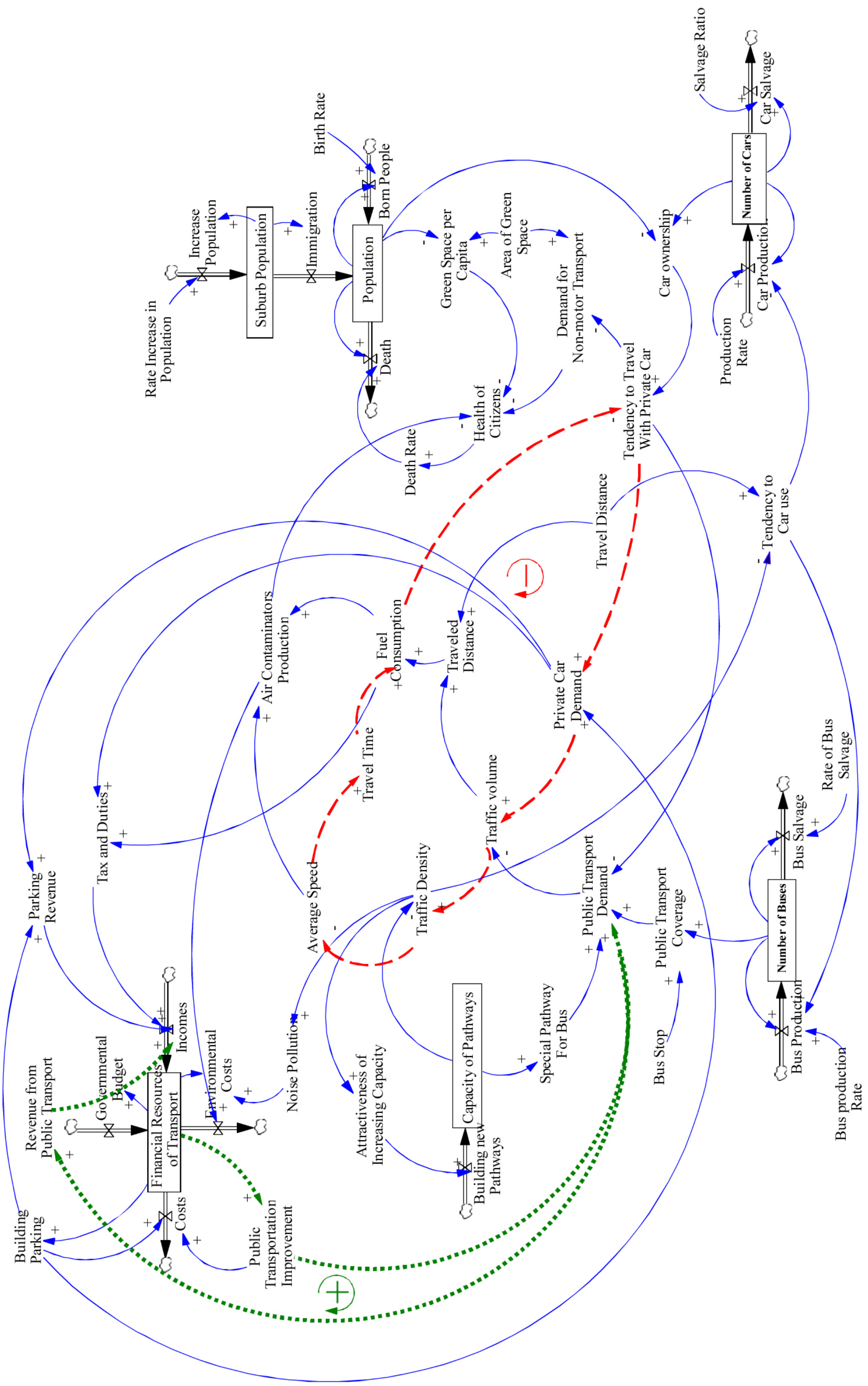

Figure 6. Flow diagram of sustainable urban transportation

4.1.2 Flow Diagram of Sustainable Urban Transportation

Flow diagram of the SUT has been created according to a causal structure. Transportation variables and those variables interacting with it, have been chosen to model SUT. Figure 6 shows the structure of the SUT model consisting of several positive and negative loops, some of which are described in the following as an example.

a) Tendency to tip by personal car (+) →Private car demand (+)→ traffic volume (+) → traffic density (+) → average speed (-) → travel time → fuel consumption (+) → tendency to tip by personal car (-)

b) Public transportation demand (+) → revenues from public transportation (+) → incoms (+) → financial resources of transportation (+) → improvement of public transportation (+) → public transportation demand (+)

The above-mentioned examples of loops have been highlighted in Figure 6. Loop (a) (shown with the red-line) has negative polarity and loop (b) (shown with the green line) has positive polarity.

4.1.3 Development of the System Dynamics Model

In this stage, mathematical equations between variables are shown in flow diagram. In this regard, using system dynamics software Vensim [Ventana System, 2009], economical, social, environmental, and transportation sub-models are modeled. Sub-models of SUT model include economy, environment, trip production and attraction, trip distribution, and modal split. These sub-models and their equations are presented in the following sections.

4.2 The Study's Sub-Models

4.2.1 The Economical Section of the System Dynamics Model

In this section, variables of financial resources of transportation, investment in intelligent systems, supplying non-marginal parking lots, and number of taxis are considered as state variables. In financial resources of transportation, income and constant governmental budget are presented as input rate variables, and costs and investment in environment are considered as output rate variables. Revenues from transportation include public transportation (bus and taxi), marginal and non-marginal parking lot, and giving tax and tolls and direct costs of investment in transportation section in improving public transportation fleet, creating pathways, investment of developing intelligent systems, parking lot construction, planning and studies, and labor cost sub-sections. It also assumed that investment in the environment is to spend in development of non-motorized transportation and renewable energies.

Unrecoverable damages of transportation are calculated from the damage has been incurred to environment and the investment to reduce negative consequences on environment. These damages are a combination of air and noise pollution, as well as water and soil contamination and waste production whose 2009 values, are shown in Table 2.

4.2.2 The Social Section of the System Dynamics Model

In social section of model, accident and number of deaths caused by accidents have been considered. Studies show that number of accidents is a function of produced and attracted trips in traffic regions [Naderan and Shahi, 2010]. Thus, in this study, a linear regression model was used to predict the number of crashes with the study's data:

$$y = 2.79 \times 10^{-5} (x_1) \qquad (2)$$

In which, x1 is the number of daily produced trips and y is the number of daily accidents.

4.2.3 The Environmental Section of the System Dynamics Model

Daily traffic volume in urban pathways can be determined by calculating annual trip demand for each vehicle and having average speed of vehicles. By dividing total traffic volume of pathways by its capacity, average traffic congestion on urban regions is calculated. Calculated delay in this section of model affects on fuel consumption of vehicles directly. Outputs of environmental sub-model include fuel consumption of gasoline and natural gas vehicles, noise pollution of heavy and light vehicles, and production of pollutants by bus, taxi, private car and motorcycle. In this regard, variables of speed and traffic congestion have been considered regarding their direct impact on these items.

Table 2. Costs of environmental pollutants per vehicle-km for year 2009

Item no	Variable	Reference	Cost (IRR)	
1	Noise pollution	[Litman, 2009]	Private car	119.78
			Bus	604.1
			Motorcycle	1211.4
2	water pollution	[Litman, 2009]	Private car	128.1
			Bus	128.1
			Motorcycle	128.1
3	Pollution due to waste production	[Litman, 2009]	Private car	3.7
			Bus	3.7
			Motorcycle	3.7
4	NO_2	[Duffill Watts, 2012]	4800	
5	CO	[Duffill Watts, 2012]	1500	
6	HC	[Duffill Watts, 2012]	1700	

Fuel consumption and emission by vehicles are functions of vehicle technology, fuel type, speed, traffic congestion, and physical conditions of pathway including linear slope and surface of pathway. In this study, fuel consumption of heavy and light vehicles has been calculated according to speed that it has been tabulated in Table 3. In Table 3, fuel consumption is estimated based on vehicles' speed, and extra consumption caused by delay will be added too. Furthermore, the functions that are needed to estimate the emissions have been acquired from studies on traffic and transportation of Tehran [Tehran's Transportationation and Traffic Studies, 1996].

Amount of emissions of different pollutants (NO2, HC, CO) by different vehicles is a function of vehicle technology, fuel type, and speed of vehicle. Functions used to estimate emissions of pollutants for each km of pathways at speed v, in grams, are calculated according to Equations (3) to (8):

$$\text{Motorcycle } CO = 76.7601/61v + 0.0095v^2 + 95.91/v \quad (3)$$

$$\text{Motorcycle } HC = 25.47 - 0.43v + 0.0024v^2 + 178.48/v \quad (4)$$

$$\text{Car and taxi } CO = 127.64 - 2.68v + 0.016v^2 + 160.12/v \quad (5)$$

$$\text{Car and taxi } HC = 6.06 - 0.10v + 0.00056v^2 + 42.57/v \quad (6)$$

$$\text{Car and taxi } NO_2 = 0.7 + 1.92/[1 + 93.54e^{-0.049v}] \quad (7)$$

$$\text{Bus } NO_2 = 19.63 - 0.32v + 0.0037v^2 + 21.13/v \quad (8)$$

In order to calculate the emission of pollutants related to each vehicle in urban regions, first, for each region, speed is determined, and using above equations, the emissions for the pollutant per km can be calculated. Then, this quantity will be multiplied by traffic volume of the vehicle and also the distance traveled.

Several methods have been introduced to calculate noise pollution in urban areas. In this study, noise pollution production model of England is the basis of calculations. In this

Table 3. Fuel consumption of heavy and light vehicles according to speed

Speed (km/hr)	Light vehicle			Heavy vehicle		
	Gas consumption (liter/km)	Extra consumption due to delay		Gasoline consumption (liter/km)	Extra consumption due to delay	
		Base consumption	Surplus consumption for each 30 sec		Base consumption	Surplus consumption for each 30 sec
16.09	0.169	0.006	0.002	0.252	0.020	0.020
32.18	0.118	0.025		0.201	0.053	
48.27	0.103	0.037		0.228	0.095	
64.36	0.108	0.048		0.279	0.133	
80.45	0.122	0.064		0.344	0.148	
96.54	0.136	0.079		0.415	0.148	
112.63	0.158	0.092		-	-	

model, variables of traffic volume (Q), speed (km/h) (V), percentage of heavy vehicles (P), and noise pollution level (db) in 10m distance (L10) regarding equation (9) are:

$$L_{10} = 10 Log_{10} Q + 33 Log_{10}(V + 40 + \frac{500}{V}) + Log_{10}(1 + \frac{5p}{V}) - 27.6 \qquad (9)$$

4.2.4 The Transportation Section of the System Dynamics Model

Classic 4-stage transportation model (UTPS, Urban Transportation Planning System) has been used to model and predict trip demand. Forecasting future trips in these models is trough four stages: trip production and attraction, trip distribution, modal split, and traffic assignment. Mashhad has been divided into 5 regions (Figure 7). This number of regions was selected so that the order of computations was reduced to a reasonable limits of time and complexity in the system dynamics model. Traffic assignment stage has not been performed in this study, because the level of aggregation of data (in only 5 regions), and the study's objective make it unnecessary. Multiple linear regressions have been used to model trip production and attraction for each region. General form of the equation in multiple linear regression analysis is shown in Equation (10):

$$T_{i/j} = a_0 + a_1 X_1 + a_2 X_2 + ... + a_n X_n \qquad (10)$$

Where:

$T_{i/j}$: number of produced trips in region i or number of attracted trips to region j

a_0, a_1, a_2… an: parameters

X_1, X_2, … Xn: dependent variables

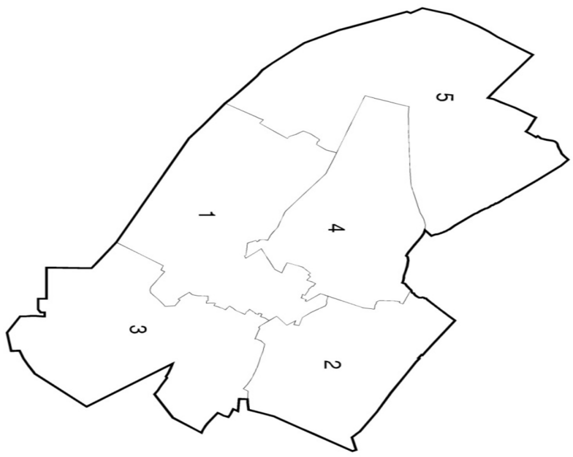

Figure 7. Definition of traffic regions in Mashhad

In this study, long term trip productions and attractions models created by studies of transportation in Mashhad have been used and variables of trip productions and attractions are shown in Table 4.

Trip distribution stage has been done using the well-known gravity model ([Ortuzar and Willumsen, 1998]. Generally, trip distribution equation is determined by equation (11):

$$T_{ij} = P_i \frac{A_j F_j K_j}{\sum_{i=1}^{n} A_j F_j K_j} \qquad (11)$$

where:

T_{ij}: number of produced trips in region i and attracted in region j,

P_i: number of produced trips by region i,

A_j: number of attracted trips toward region j,

Table 4. variables of trip Production and Attraction models [The Institute for Transportationation Studies & Research, 1995]

Trip Productions	Number of workers in traffic region i	Trip Attractions	Employment level in traffic region j
	Employment level in traffic region i		Car ownership of residents in traffic region j
	Car ownership of residents in traffic region i		Number of students of universities in traffic region j
	Number of students in traffic region i		Number of high school classes in traffic region j
	Number of students of universities in traffic region i		Number of primary and secondary school classes in traffic region j
	Population of traffic region i		Number of hospital beds in traffic region j
	Population of Mashhad		Population of traffic region j
	Family size in traffic region i		Population of Mashhad
	Family size in Mashhad		Area of parks in traffic region j (hectares)
	Air distance between traffic region i and Holy Shrine (km)		Maximum air distance traffic region j and Holy Shrine and 5 km

F_{ij}: deterrence function, usually Fij is used as $(\frac{1}{t_{ij}^{b}})$ where trip duration between regions i and j, t_{ij} and also b are constant, and

K_{ij}: coefficient reflecting social and economical interrelationships between regions i and j

In the current system dynamics model of SUT, it is assumed that b = 2 and K_{ij} = 1.

Next stage of forecasting future trips, modal split, is to determine percentage of users of each existing mode. In each trip, passengers choose one of the available modes including private car, public transportation, bicycle, and walking. The selection is a complicated process which depends on characteristics and type of trip, characteristics of passenger, and the mode's specification [Ortuzar and Willumsen, 1998; Khisty and Lall, 2003].

In modal split stage, firstly, demand for trips by motor vehicles and non-motorized vehicles separated. Demand for trip by non-motorized vehicles include walking and cycling, demand for trips by motor vehicles is obtained by deducting this amount from total trips between region i and j. Then, users of motor vehicles are divided into two categories: ones who have private vehicle and ones who don't have. The reason of this division is to increase accuracy in changing indicators and trip utilization due to change in foreseen policies for different groups of passengers.

Transportation modes are divided into two categories: public (bus and taxi) and private (private car or motorcycle). Portion of usage of each mode is determined by utilization of each one. Effective factors (utilities) in tendency to trip by each mode include travel time, travel cost, and mode quality. Tendency to trip by each mode is obtained by sum of utility coefficient multiplied by utility weight. According to other studies, time, cost, and quality weights are assumed 0.45, 0.33 and 0.22 respectively [Vakili et al., 2008].

5. Validation of the Model

In order to be able to validate a model, a widespread way is to utilize real data. The validation of model is measured by coefficient of determination (R2), and eventually year 2009 has been considered as base year of transportation planning in this study.

5.1 Model Validation

In this stage, the results of some model variables are validated in target year (2009). In this regard, coefficient of determination (R2) has been used. Evaluated variables include population, working population, car ownership, motorcycle ownership, number of primary and secondary school classes, and daily produced and attracted trips. In Table 5, some important variables of trip production and attraction are shown. Fitting coefficient for population, working population, car ownership, motorcycle ownership, and number of primary and secondary schools' classes are calculated 0.867, 0.923, 0.924, 0.978, and 0.891 respectively. Therefore, these variables are near 1, results are evaluated appropriate. Figure 8 has been determined coefficient of determination of car and motorcycle ownership. Afterwards, evaluation of daily produced and attracted trips has been evaluated for work, education, recreation, personal business, pilgrimage, and also non-home-based objectives. Determination coefficient for total trip production and attraction in urban regions are 0.995 and 0.927.

5.2 Discussion

The objective of this stage is to determine the sensitivity of the model to the variations of its parameters. In this regard, average car occupancy and salvage rate of vehicles have been

Table 5. Comparison between variables of trip production and trip attraction models, observed and resulted from model in 2009

Region		Population	Working population	Car ownership	Motorcycle ownership	Number of primary and secondary school classes
Observed	1	324982	88619	0.114	0.158	3015
	2	666238	159336	0.0595	0.163	4808
	3	419538	104585	0.0636	0.166	3599
	4	627786	170787	0.131	0.135	5096
	5	689094	176538	0.081	0.089	4746
Predicted	1	380652	97105	0.160	0.151	2852
	2	694000	158231	0.041	0.172	5199
	3	440955	102073	0.066	0.165	3304
	4	629840	161084	0.162	0.132	4719
	5	581761	148788	0.065	0.079	4358

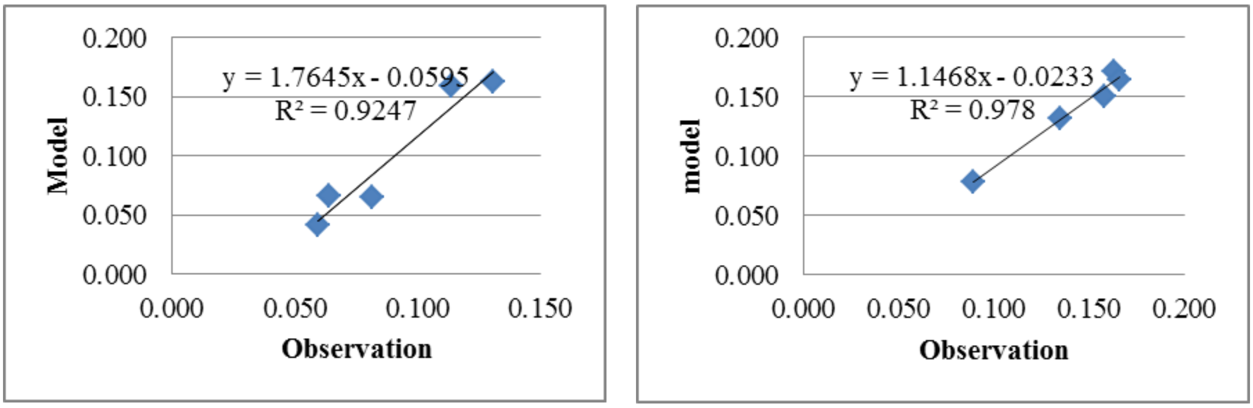

Figure 8. Coefficient of determination value in car (left) and motorcycle (right) ownership per capita variables

chosen from sub-models of section 4, and values for two indicators from the validation year (2009) to horizon (2044) have been evaluated. Values of these variables are shown in Table 6 in five different options (policies). Environmental index of annual gasoline consumption, and transportation index of average traffic congestion. Sensitivity analyses for these indicators are shown in Figures 9 and 10. In these figures, horizontal axis shows years from zero to fifty. 1994 is considered as the base year, 15th year as the current (validation) year (2009), and 50th year as the long-term forecast year (2044).

Annual gasoline consumption in Mashhad has an approximately constant trend until 2014, and after that it has increased significantly; and the reason is an increase in public transportation fleet and tendency to use public vehicles. Again, when the average private car occupancy increases, annual gasoline consumption decreases significantly; whilst in analysis related to salvage rate of vehicle, while this variable increases, annual gasoline consumption is constant until 2014 and after that decreases in a stepwise pattern.

Index for average traffic congestion increases in both of the analysis, and by increase in average private car occupancy and salvage rate of vehicles, it decreases gradually and in a step manner respectively.

Table 6. Selected variables for sensitivity analysis of sustainable urban transportation model

Parameter	Initial Value	Option1	Option2	Option3	Option4	Option5
average car occupancy	1.7	1.87	2.21	2.74	3.4	4
salvage rate of vehicles	0.002	0.003	0.004	0.006	0.008	0.01

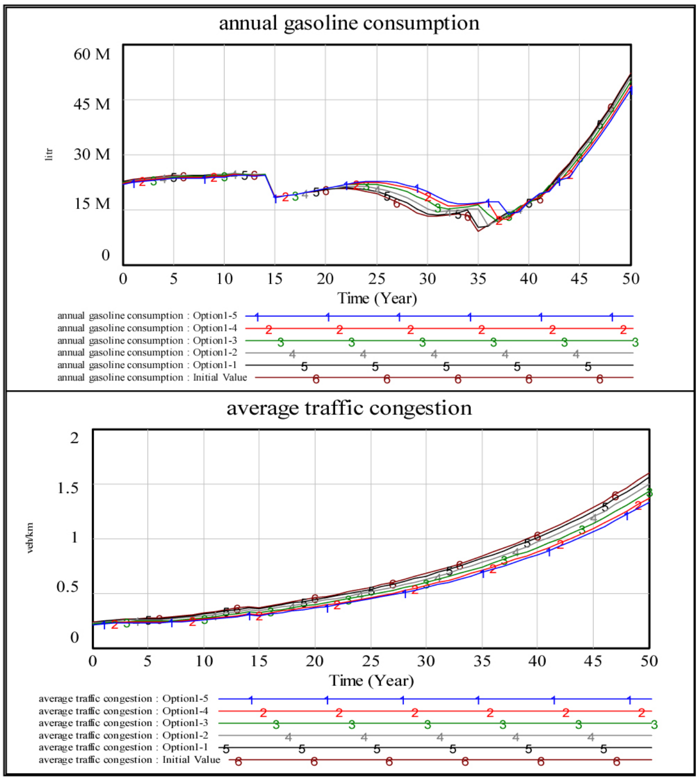

Figure 9. Changes of indicators in time with respect to different options of average car occupancy

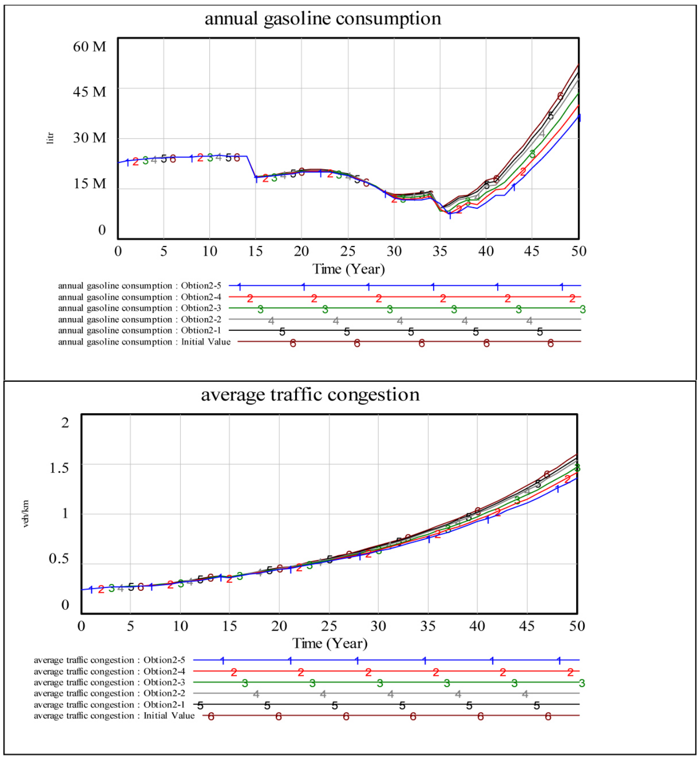

Figure 10. Changes of indicators in time with respect to different options of salvage rate of vehicles

6. Conclusion

Due to the growing concern about the undesired consequences of development in the urban transportation, achieving a sustainable transportation in cities is an accepted strategy among the decision-makers. According to a popular definition for sustainable development, the concurrent interaction among economic, social, and environmental features of urban transportation should be equally considered in a sustainability study, and this makes such studies more complicated. In the current paper, the situation of Mashhad transportation during 1994 to 2044 using a system dynamics model has been portrayed. The system dynamics models are able to consider the simultaneous influence of different variables on each other. Therefore, they are good approaches for monitoring the status of economy, environment, and social factors resulting from transportation. In order to model Mashhad transportation, firstly the city was partitioned to five regions and the model was calibrated and validated for the year 2009 (base year).

Monitoring 28 selected indicators in the model showed that continuing the current policies would result in the increase of various problems and consequently non-sustainability. Therefore, the effects of two policies namely "increasing average car occupancy", and "increasing salvage rate of vehicles" were analyzed. The assessments showed that increasing salvage rate of vehicles had superior effects on minimizing the annual fuel consumption. Because it increased the utility of public transportation, reduced traffic congestion, and consequently reduced travel time and fuel consumption. The other policy that is increasing average car occupancy didn't show comparatively promising results in the sustainability indicators.

The proposed approach in the current paper, has the capability of assessment of different transportation policies in the extent of minimizing negative indicators and maximizing positive ones (according to Table 1). The authors suggest that the combination scheme of different policies is analyzed for further research.

7. References

-ASTRA. (1999) "Design and specification of a system dynamics model", ASTRA Deliverable 2.

-Bakhshandeh, R, Shahgholian, K, and Shahraki, A. (2013) "Model for reduce flights delays using system dynamics (Case study in Iranian Airports Company)", Interdisciplinary Journal of Contemporary Research in Business, January, 4(9): pp.746-757.

-Chen, M. C., Ho, T. P., Jan, C. G. (2006) "A System Dynamics Model of Sustainable Urban Development: Assessing Air Purification Policies at Taipei City". Asian Pacific Planning Review 4(1): 29-52.

-Deputy of Energy Affairs. (2003) “Energy balance sheet 2002 (in Persian)”, Tehran, Iran Ministry of Energy.

-Development Committee (1987) “Environment, growth and development”, Washington, D.C. U.S.A., Joint Ministerial Committee of the Boards of Governors of the World Bank and the International Monetary Fund on the Transfer of Real Resources to Developing Countries (Development Committee): Available from the World Bank Sales Unit.

-Duffill Watts PTE Ltd. (2012) “Mashhad Traffic Restricted Area Revision and Extension Study Model Application – Technical Note”, Traffic & transportation Organization Mashhad, Mashhad.

-Habibian, M. and Ostadi Jafari, M. (2013) “Assessing the role of transportation demand management policies on urban air pollution: A case study of Mashhad, Iran”, U.S.-Iran Symposium on Air Pollution in Megacities, National Academies of Sciences and Engineering, Beckman Center in Irvine, CA, 3-5th Sep, CA, USA.

-Institute for Transportationation Studies and Research (1995) “Forecasting travel demand for 2001”. Mashhad Comprehensive Urban Transportationation Planning. Tehran, Iran, The Institute for Transportationation Studies & Research, Report No. 7604

-Khalatbary, F. and Atwan, M. (2008) “A strategic look at energy economics in transportationation sector (in Persian)”, Tehran, Iran, Shadan.

-Khisty, C. J. and Lall, B. K. (2003) “Transportationation engineering : an introduction”, Upper Saddle River, N.J., Prentice Hall.

-Litman, T. (2009) “Transportationation cost and benefit analysis II – Vehicle costs” www.vtpi.org.

-Naderan, Ali and Shahi, Jalil (2010) “Aggregate crash prediction models: Introducing crash generation concept”. Accident Analysis & Prevention 42(1): 339-346.

-Ortuzar, D. and Willumsen, L. G. (1998) “Modelling transportation”, John Wiley and Sons Ltd.

-Rassafi, A. A., Poorzahedy, H. and Vaziri, M. (2006) “An alternative definition of sustainable development using stability and chaos theories”. Sustainable Development 14(1): 62-71.

-Rassafi, A. A. and Vaziri, M. (2005) “Sustainable transportation indicators: Definition and Integration”. International Journal of Environmental Science and Technology 2(1): 83-96.

- Rassafi, A. A. and Vaziri, M. (2007) “Assessment of modal transportationation sustainability: Application of data envelopment and concordance analyses”. Iranian Journal of Science and Technology Transaction B-Engineering 31(B2): 179-193.

- Schade, W. and Rothengatter, W. (1999) “Long-term assessment of transportation policies to achieve sustainability”. The 4th European Congress on Systems Science. Valencia, Spain.

- Sterman, J. (2000) “Business dynamics: systems thinking and modeling for a complex world”, Boston, Irwin/McGraw-Hill.

- Tehran’s Transportationation and Traffic Studies (1996) “The final structure of transportationation model for Tehran in EMME/2 environment (in Persian)”, Tehran’s Transportationation Comprehensive Plan. Tehran, Iran. Report No. 117.

- Vakili, K., Isaai, M. T. and Barsari, A. J. (2008) “Strategic assessment of transportationation demand management policies: Tehran Case Study”, The 2008 International Conference of the System Dynamics Society, Athens, Greece.

- Ventana System Inc. (2009) “Vensim® PLE, Personal Learning Edition User’s Guide, Version 3.0”.

- Wang, J., Lu, H. and Peng, H. (2008) “System dynamics model of urban transportationation system and its application”, Journal of Transportationation Systems Engineering and Information Technology 8(3): pp.83-89.

- World Commission on Environment and Development (1987) “Our common future”, London, Oxford University Press.

- Zhang, L. and Wei, Y. (2013) “The definition and connotation of the sustainable urban transport”, Applied Mechanics and Materials (Volumes 253 - 255): 254-262, Available from: www.scientific.net/AMM.253-255.254