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Macro-scale Evaluation of Urban Transportation Demand Managements Policies in CBD by Using System Dynamics Case study: Isfahan CBD

Shahrzad Khosravi[a], Hossein Haghshenas[b*], Vahid Salehi[c]

[a] M.Sc. Transportation Planning, Transportation Department, Isfahan University of Technology, Isfahan, Iran
[b] Assistant Professor, Transportation Department, Isfahan University of Technology, Isfahan, Iran
[c] M.Sc. Transportation Planning, Transportation Department, Isfahan University of Technology, Isfahan, Iran

Abstract

Traditional transportation planning methods that are appropriate for a partial analysis in traffic area zone levels require extensive data collection and only could be used to evaluate and compare a few number of demand management policies with limited criteria. In this paper, system dynamics modelling has been used to evaluate transport demand management policies. System dynamics is a suitable method for long-term macro-scale evaluations of different policies with various indicators, because in this method, causal relationships between variables and their feedbacks are considered as well as its dynamic approach. In this research, encouraging policies like improving the bus and taxi services, completing metro network development, improving bicycle facilities and encouraging to carpool as well as restrictive policies like cordon pricing policies, increasing parking prices, and odd-even policy and also simultaneously applying some of the encouraging policies and effective restrictive policies in the form of a policy package are being investigated in the central business district of Isfahan city. Urban transportation causal loops were conceptualized and the dynamic relations among urban transportation variables were created to develop the pertinent urban dynamics model. Efficacious transportation policies, which will be implemented for ten years, will be ranked in accordance with monitoring three indicators of air pollution, energy consumption and traffic mobility. Respectively, completing metro network development, BRT network development are the most effective policies and completing metro network development simultaneously with cordon pricing has been the most effective combined policy.

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Keywords: demand management; CBD; system dynamics; policy making; mode choosing.

1. Introduction:

The traffic volume approaching the capacity of the streets is one of the biggest urban problems, which leads to increased traffic congestion and bustling streets. In congested centripetal cities, the growth of urban traffic and the presence of historical monuments and tourist attractions in the central area of the city has become a traffic and transportation problem. The important issue of determining the selection process and the type of travel demand management policies for reducing the problems caused by increased traffic requires a comprehensive understanding of the behavioural consequences of implementing different policies in each region (Vieira et al. 2007).

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The management of travel demand is referred to as the set of strategies that make optimal use of transport resources. The purpose of travel demand management is to influence the travel behaviour of people to use less costly means of transportation and ultimately reduce traffic congestion. So far, various studies have been conducted in evaluating demand management policies.

Thorpe et al. (2000) have conducted a comparative study between the cities of Cambridge and Newcastle in relation to the acceptance and effectiveness of demand management methods. In this study, the policy of charging network users for associated fees, improving the public transport system, increasing parking fees and limiting the traffic of private cars in the central urban areas has been studied. The results indicate that improving the public transportation system is clearly more acceptable than restrictive policies. In contrast, the increase in parking costs has been the least acceptable policy. Additionally, user charges has been shown to be slightly more acceptable (about %5) than traffic constraints (Thorpe et al. 2000).

In a study based on an online interview by Arentze et al., the way individuals set their daily activity schedule in response to a new policy has been studied. They described several discrete selection models to investigate the reactions of individuals to different pricing scenarios. According to the collected responses, multiple logit of how to set the travel time, route, destination, mode of transportation and frequency of daily travel of individuals were modelled on two prices, according to the cordon pricing scenarios. Results of the stated adaptation experiment suggest that changing route or departure time is the most important way of adapting work trips, whereas public transport and working at home play a more limited role. For non-work activities changing route and switching to bike are the dominant responses (Arentze et al. 2004).

Washbrooke et al. have stated that one option for minimizing external costs associated with emissions, congestion, noise and other impacts, is to introduce road pricing and parking charges to reduce demand for single occupant vehicle (SOV) use, while providing improvements to alternatives to encourage mode switching. However, the impact of these policies on urban mode choice is uncertain, and results reported from regions where charging has been introduced may not be transferable. In particular, revealed preference data associated with cost recovery tolls on single facilities may not provide a clear picture of driver response to tolls for demand management. In the research of Washbrooke, to estimate commuter mode choice behaviour in response to such policies, 548 commuters from a Greater Vancouver suburb who presently drive alone to work completed an individually customized discrete choice experiment (DCE) in which they chose between driving alone, carpooling or taking a hypothetical express bus service when choices varied in terms of time and cost attributes. Attribute coefficients identified with the DCE were used in a predictive model to estimate commuter response to various policy oriented combinations of charges and incentives. Model results suggest that increases in drive alone costs will bring about greater reductions in SOV demand than increases in SOV travel time or improvements in the times and costs of alternatives beyond a base level of service. The methods described here provide an effective and efficient way for policy makers to develop an initial assessment of driver reactions to the introduction of pricing policies in their particular regions.(Washbrook et al. 2006).

Erickson et al., with a focus on improving public transportation, increasing fuel prices, and a combination of both as a policy package, concluded that combining two policies would be more effective than one of these policies. In this scenario based study, the expected car use reduction in response to one restrictive policy measure (i.e. raised tax on fossil fuel), one encouraging policy measure (i.e. improved public transport), and a combination of the two measures were analysed. The aim was to compare the expected car use reduction in response to the different TDM measures, the car use reduction strategies used to achieve this reduction, and factors important for the expected car use reduction (i.e. background factors, internal motivational factors (general intention and personal norm), and perceived personal impact of the measure). Results demonstrated that the combined measure led to larger expected car use reduction compared to the measures evaluated individually and the reduction was mainly expected to be made by means of trip chaining and changing travel mode. Moreover, internal motivational factors, such as personal norm or general intention, and the perceived impact of the measure, were found to be important for the expected car use reduction in response to the TDM measures (Eriksson et al. 2010).

Sall et al. conducted a study to evaluate the performance of the San Francisco County Transportation Authority’s recently-enhanced Nine-County Regional Pricing Model (RPM-9), which is being used to study congestion pricing alternatives in San Francisco as a part of the Mobility, Access, and Pricing Study. This study sought to evaluate comprehensive pricing and mobility-enhancing packages to improve access and offer more sustainable travel choices to and within San Francisco. The Study tested various pricing scenarios including cordon, area, and gateway designs; various toll levels; and a range of shoulder pricing/time of day profiles. Pricing scenarios were coupled with strategies for improving accessibility for all modes of travel to, from, and within San Francisco including, but not limited to, local and regional transit investments. RPM-9's structure as a tour-based microsimulation model allowed several enhancements for this study that would not have been possible in a trip-based framework. These include the use of value-of-time distributions, rather than averages across groups; the feedback of mode and destination choice log sums to make auto ownership and tour generation sensitive to price; the explicit tracking of travellers who have paid area tolls; and enhanced peak spreading models. The disaggregate nature of RPM-9 facilitated summaries of key measures of effectiveness at various levels and types of aggregation including income level, residential location, and work location. These flexible summaries were critical to evaluating alternatives and answering questions about who was paying versus who was benefiting (Sall et al. 2010).

Habibian and Kermanshah examined the role of transportation demand management (TDM) policies on commuters' mode choice in the city of Tehran. The analysis is based on the results of a stated preferences survey developed through the design of experiments approach. Five policies covering increasing parking cost, increasing fuel cost, cordon pricing, transit time reduction, and transit access improvement are assessed in order to study their impact on commuters' consideration of six modes of transportation to travel to work. A multinomial logit model was developed for the 366 commuters who regularly commute to their workplace in the Centre of the city. In addition to a number of commuting and contextual variables, the model shows that the single policies main effect and multiple policies interactions are significant in affecting commuters' mode choice. The marginal effects of policies are presented, and simultaneous effects of the policies on car usage variations are provided (Habibian and Kermanshah 2013).

In the research of Mansouri et al. attempts were made to analyse the type, degree and the place of effects of different travel demand management policies so that the most efficient one could be prioritized based on its potential and its degree of effect. To do so, a questionnaire was designed using the revealed preference method and distributed among 480 respondents within the central business district of Isfahan city. The findings revealed the effects of the policies on personal, socio-economic and travel characteristics of the individuals. By using sensitivity analysis, Mansouri et al. investigated the effect of various travel demand management policies on the non-use of private cars in the central business district of Isfahan. In this research, 10 restrictive and encouraging policy tools were considered for evaluation and distributed in 480 questionnaires among private and public transport users. The results of the questionnaires showed that encouraging policies are more than twice as effective as restrictive policies. Decreasing the travel time and increasing comfort in the group of restrictive policies and rising fuel prices and parking prices in the restrictive policy group had the most influence on private car usage. Using interview data, four different restrictive scenarios were proposed to address the city's central business district traffic constraints as a long-term policy and the quantitative and qualitative improvements of the current fleet of public transportation and the establishment of a public transport network in the city Centre as mid-term policies (Mansoori et al. 2016).

The conventional method of four-stage transport planning models that are suitable for a partial analysis of changes in traffic area levels requires extensive information and, due to information constraints and math models, are usually usable to evaluate a limited number of demand management policies. The preference-based interviewing methods, due to the information gathering method, face limitations in terms of generalizing the city and modelling different policies. Therefore, these approaches to large-scale assessment of a large number of urban transport policies are not appropriate.

The main innovation of this paper is the use of a system dynamics model for evaluating various demand management policies in the city's central area, which has not been the same in previous studies. One of the important advantages of this approach is the suitability to assess a large number of demand management policies based on various indicators. Some of the advantages of using system dynamics models are simplicity, being logical and systematic it has the ability to check system performance from a variety of aspects, and the ability to simulate complex systems, as well as dynamic communication of cause and effect, makes modelling in both linear and nonlinear and behavioural delays a possibility, and provides linkages between models and issues. The application of this study provides a method for determining the highest demand management policies for the city's central business districts and its application to help city managers and policymakers in decision making and implementation of demand management policies.

In this research, encouraging policies such as improving the bus and taxi services, completing metro network development, improving bicycle facilities and encouraging to carpool are being investigated, as well as restrictive policies such as road and cordon pricing, increasing parking prices, and odd-even policy within the central business district of Isfahan city.

The article is set in 5 sections. In Section 2, transport studies in which system dynamics models has been used are reviewed. Section 3 includes a description of how to construct a dynamic model. In Section 4, the modelling of demand management policies is investigated. The results of the evaluation of management policies are being represented in section 5, and section 6, includes a general conclusion.

2. Literature of system dynamics models:

System dynamic models are capable of examining the relationships between phenomena over time and predicting future developments based on systems thinking. In system dynamics models, variations of the system over time are investigated using differential equations, considering whether the time is discrete or continuous. In these models, the systems thinking is the same as the analyst's perceptions of the network set of causes and changes that determine how the system works. In dynamic systems, there are various tools for displaying the model and providing the causal structures of the problem. These tools include model boundary graphs, subsystem diagrams, causal diagrams, flow diagrams, and mathematical equations and delays.

The model boundary graph shows the range of the model by listing the endogenous, exogenous, input and output variables, and the variables that affect the model. The subsystem diagram depicts the overall architecture of the model. The relationships between variables are represented by causal diagrams. In state-flow diagrams, state variables represent the state of the system from the population of road inventories, debts, and capital book value. The rate variables represent the rate of system change, such as the rate of mortgage rate increase, investment rate and capital depreciation. Mathematical relations between variables are the other components of a system dynamics model that reduce cause-effect relationships and rate flows (Haghshenas et al. 2015).

So far, in some transport studies, a dynamic system approach has been used. Wang et al. examined the modelling method based on the system dynamics model in transportation systems and its application. In this study, they explore different aspects of using this method, the applications and the positive and negative points provided to users. They considered transportation systems as complex systems in which many factors are involved, and the effects of all factors should be properly studied on each other. Wang et al. set to devote to the modelling of the Dalian city of China and considered four variables of population state, gross production, routes lengths, and future production in their model. In the end, after examining mathematical relationships, examine the effects of different policies over the period of 50 years. This paper presents a system dynamics approach based on the cause-and-effect analysis and feedback loop structures. The proposed SD model comprises 7 sub models: population, economic development, number of vehicles, environmental influence, travel demand, transport supply, and traffic congestion. The model runs in Vensim PLE software using the data from Dalian, China. The coefficient of the intervention policy of vehicle ownership is chosen as the control variable for simulation, and the impacts of different policy scenarios on urban development and transportation system are analysed. It suggests that Dalian should restrict the total number of vehicles to improve the sustainability of transportation system. (Wang et al. 2008).

Shen et al. (2009) have applied a system dynamics model for the sustainable land use and urban development in Hong Kong. The model is used to test the outcomes of development policy scenarios and make forecasts. It consists of five sub-systems including population, economy, housing, transport and urban/developed land, respectively. Two distinctively different development schemes concerning urban population density are simulated by the model and the findings are undertaken to verify the model through comparison with historical data and sensitivity check. The forecast timeframe is then expanded from 40 years to 300 years, providing a simulation period long enough to observe and study the ‘‘limits to growth’’ phenomenon and the impacts on development potential of Hong Kong. The modelling results are directly useful to compare different dynamic consequences brought by various policies and decisions, and are thus of great significance to achieving the goal of sustainable land use (Shen et al. 2009).

The research of Liu et al. provides a modelling framework based on the system dynamics approach by which policy makers can understand the dynamic and complex nature of traffic congestion within a transportation socioeconomic system representation of a metropolitan area. This framework offers policy makers an assessment platform that focuses on the short- and long-term system behaviours arising from an area-wide congestion pricing policy along with other congestion mitigation policies. Within this framework, improved bus and metro capacities contribute to the supply dynamics which in turn affect the travel demand of individuals and their choice of different transportation modes. Work travel and social networking activities are assumed to generate additional travel demand dynamics that are affected by travellers’ perception of the level of service of the different transportation modes, their perception of the congestion level, and the associated traveling costs. It is assumed that the, population, tourism and employment growth are exogenous factors that affect demand. Furthermore, this paper builds on a previously formulated approach where fuzzy logic concepts are used to represent linguistic variables assumed to describe consumer perceptions about transportation conditions. In this study, the dynamic effects of pricing policy on the social and economic transportation system in a wider region are investigated using the system dynamics modelling method (Liu et al. 2010).

Armah et al. (2010), have presented a model for transporting part of the city of Ghana, which produces pollutants. Accra, the capital of Ghana, faces urban planning problems such as air pollution, traffic safety and land use planning. The paper aims to provide a system dynamics perspective of the problems. Most of the drivers and cause-effect relationships of traffic congestion and its attendant air pollution are investigated and analysed using causal loop diagrams. The paper further suggests mechanisms by which the negative externalities associated with road transport in the city of Accra can be addressed. The main output of the model is the amount of pollutants that depends on the volume of traffic, the length of roads and the number of vehicles. Armah et al. Used a model for surveying the city and used the model to evaluate supply and demand management policies (Armah et al. 2010).

Rassaf (2013), has developed a conceptual model for transport communication with the city's environmental, economic and social dimensions. In this paper, a comprehensive model is developed using a system dynamics approach to evaluate sustainable urban transportation. This model includes social, economic, 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. By changing some of the variables, various scenarios have been made on the impact of various transport policies, such as the collection and recycling of depreciated vehicles, the development of hiking and bicycle facilities, and the reduction of single-passenger vehicles, and in each case the changes in the indicators have been examined. Based on that, top policies have been introduced in Mashhad, respectively, to reduce single-passenger vehicles and develop a culture of hiking and cycling (Rassaf et al. 2014).

Vafa-Arani et al. (2014) stated that the air pollution is known as a complex system for evaluation due to the existence of various strategies for studying and controlling and engaging in many subjects and sciences. In this research, the effects of various factors such as urban transportation, air pollution caused by the industry and other cases have been considered, and also factors influencing their expansion or control have been discussed. In line with that, a system dynamics model is proposed in order to estimate the behaviour of parameters affecting air pollution in Tehran. The proposed model includes two subsystems: (1) urban transportation, (2) air polluting industries. In this paper, several policies are proposed to mitigate air pollution. The proposed model is simulated under several scenarios using historical data of transportation and industrial sectors in Tehran. Policies are categorized as: (1) road construction, (2) technology improvement in fuel and automotive industries, (3) traffic control plans, (4) development of public transportation infrastructures. The results show effectiveness of the proposed policies. In this case, technology improvement in fuel and automotive industries and development of public transportation infrastructures are more effective policies in order to reduce air pollution. (Vafa-Arani et al. 2014).

Haghshenas et al. (In 2015) examined the sustainable transportation in Isfahan using information from other cities based on a system dynamics model. After analysing the influential factors and models of production and distribution of travel, they developed their own dynamic system and verified it with the help of information from the cities of the world. The authors, using a dynamic model, have studied the results and effects of these scenarios on the future of sustainable transport of Isfahan using existing information in Isfahan City and the creation of different scenarios in Isfahan. It should be noted that the built model has usability in other parts of the world (Haghshenas et al. 2015).

In the studies, the overall transport situation in a city has been modelled in general, and no study has been made that studies the different demand management policies in the centre of a city.

3. Building a system dynamics model:

Among the models, system dynamical models are considered as a suitable method for long-term evaluations in comparison with other models due to the consideration of causal relationships and the feedback between variables and the inclusion of latency or non-niche effects of parameters over time. The elements of the dynamical system model include independent variables (cause), dependent variables (effect) and arrows indicating the relationship between cause and effect. The relationship between these variables results in the formation of feedback loops. In general, the process of constructing dynamic system models consists of three phases of conceptual modelling, flow diagram drawing and development of a dynamical system model in one of the dynamical systems software. The analysis of dynamic systems in this research is done using the Vensim system analysis software. The dynamic model of this research shows the relationship between transport variables in Isfahan city at macro-scale levels. The central district considered for this study is as seen in figure1. The trips that are either originated or destined in this area are examined in this study. This district includes the central core of Isfahan city and is smaller than the second belt of highway ring. in fact, it corresponds to the central area of the city including the 1st and 3rd district of Isfahan municipality.

The historic centre of Isfahan, with its attractive travel, office, business, educational and medical facilities, attracts around 400,000 daily trips. The limited capacity of the central city streets cannot meet the demand for the attracted trips, and urban managers have turned to demand management policies. Accordingly, a cordon pricing plan is going to be implemented in the future. At the same time, BRT lines are also going to be expanded in the city. The scope of the implementation of the cordon pricing plan and the establishment of BRT lines is based on the proposal of executive official transportation studies of Isfahan (Fig. 1.).

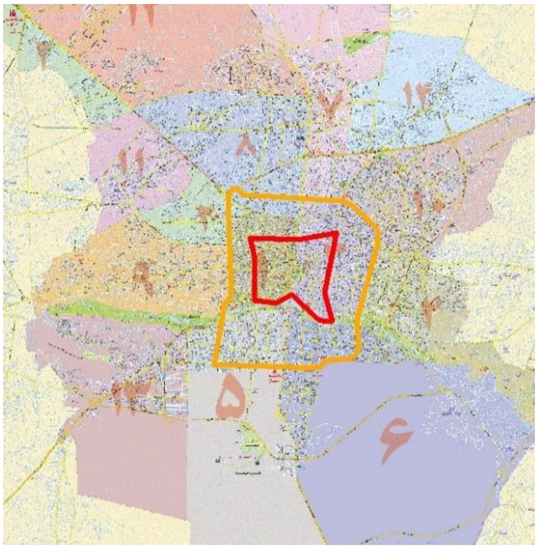


Fig. 1. The location of the cordon pricing plan

4. Examination of Cause-Effect Relationships:

The causal relationships, rings, and variables of the model made for this research are as seen in figure 2. Input variables are coloured yellow and output variables are coloured green.

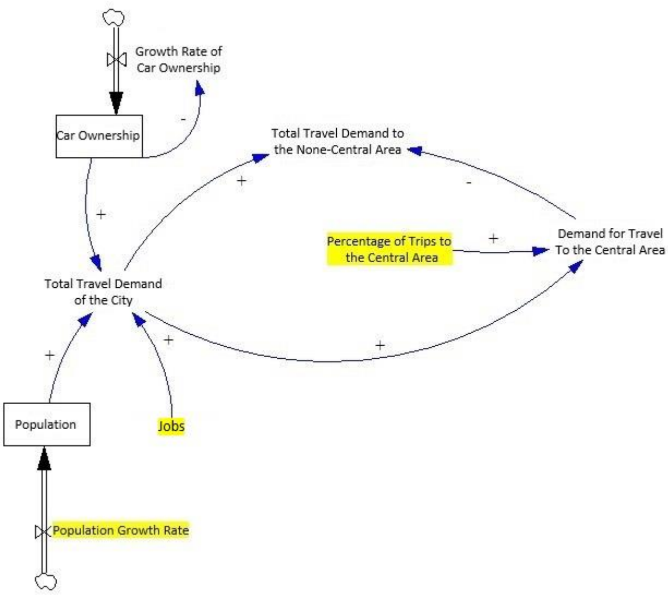


Fig. 2. Causal diagram of the travel demand of CBD

In this model, the city of Isfahan is divided into two central and non-central districts. The total demand for the whole city of Isfahan is also influenced by three variables of population, car ownership and employment. All of these three variables have a direct relationship with the total travel demand. Population variable increases with a certain growth rate. Also, car ownership rises at a definite rate, and this rate will slowly increase over time as car ownership increases. The total travel demand of the city is divided into two segments of demand for travel to the central area and travel demand for the non-central area.

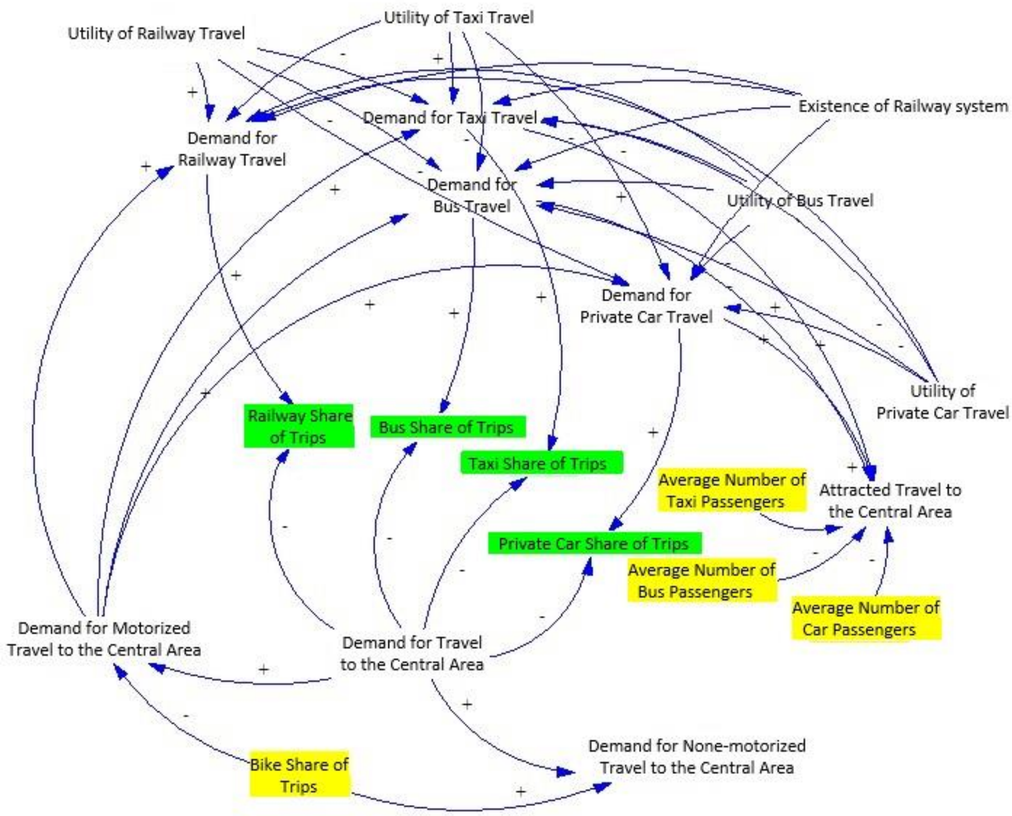


Fig. 3. Causal diagram of transporting modal share

In the model that has been used in this research, motorized and non-motorized travel demands are demarcated to the central district. This breakdown is done using the input variable of the bike's percentage of trips. In the following, four types of transport, as described in figure 3, are discussed for the city: 1- private car trip (including motorcycle), 2- taxi travel, 3- bus travel, and 4- traveling using railway transport. Considering the variable existence of the rail system in the model, it is possible to examine the impact of metro network in Isfahan.

The demand for motorized travel for the central district of the city is positively correlated with the demand for private car transport, taxi travel demand, bus travel demand, and rail travel demand. For any transportation mode, an indicator of utility is also considered. The demand for travel with any mode is affected positively by the utility indicator of the same mode. Also the demand for each mode is affected negatively by the utility indicator of other three modes. By increasing the demand for private car travels, taxi travel, and bus travel, travel attraction to the district will be higher according to the average number of passengers. Also, the percentage of each transportation mode is obtained by dividing the demand for travel with each mode by the travel demand of the central area.

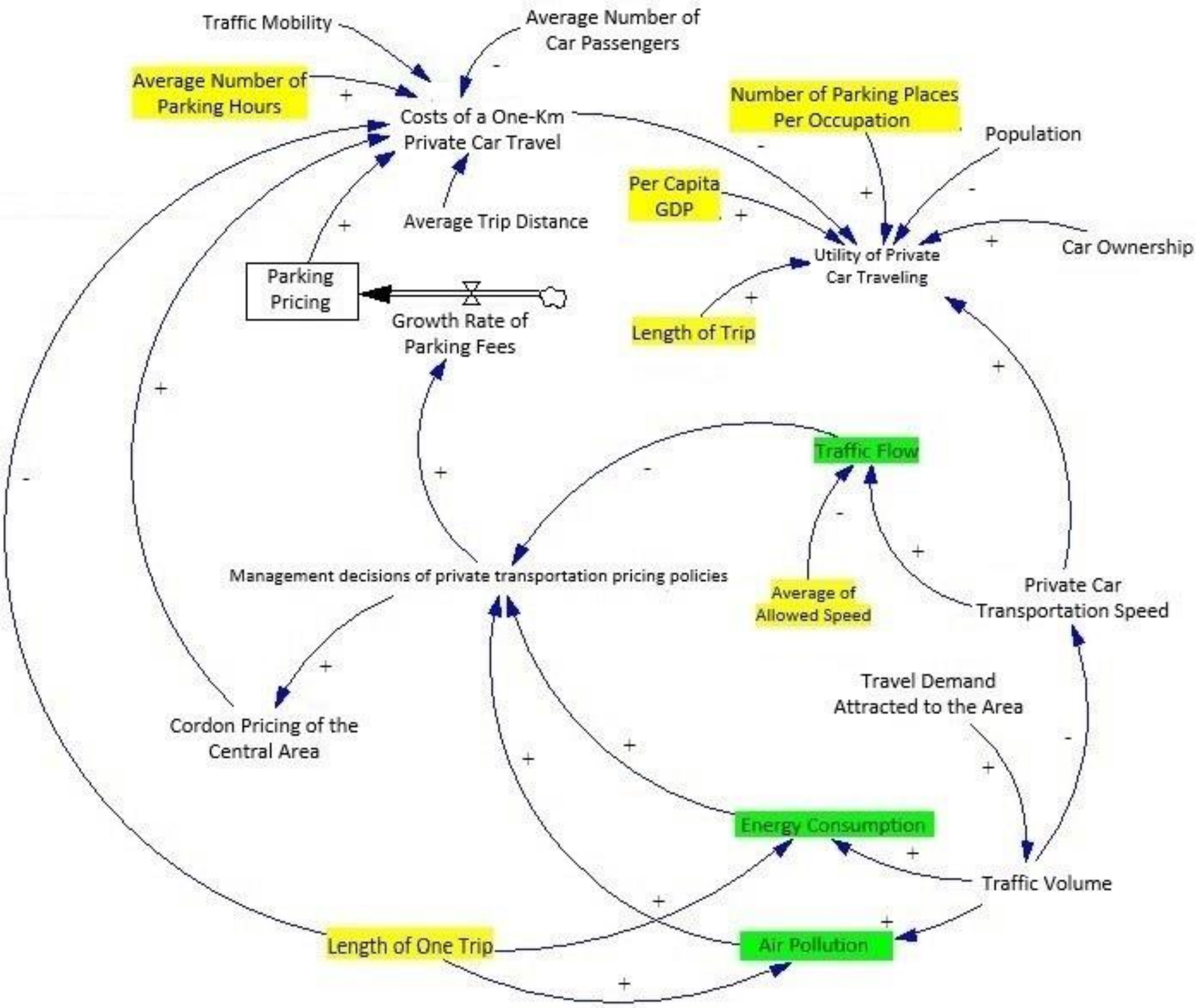


Fig. 4. Causal diagram of models outputs

The utility of travelling by a private car is affected by variables: length of travel, per capita GDP, costs of a private car in terms of length, number of parking spaces per occupation, car ownership, and average private car travel speed. The cost of a one-kilometre private car travel is influenced by the number of average car passengers, the average number of parking hours, the distance of a trip, parking prices, and the cordon pricing. Cordon price and parking prices are determined by the management decisions of the private car transportation pricing policy.

These pricing are based on cordon pricing management policies and parking prices rises. The management decisions of the private car transportation pricing policies are based on the three indicators of air pollution outflow, energy consumption and traffic flow. In this section, using the Trans CAD software, the relationship between the volume of traffic and the demand for travel attracted to the central area of the city has been obtained, as well as the relationship between the volume of traffic and the speed of private transportation. Energy consumption and air pollution are influenced by variables of traffic volume and the length of a trip. Variable of traffic flow also results in the division of private car transport speed into allowed speed, which are determined in accordance with Urban Design Guidelines.

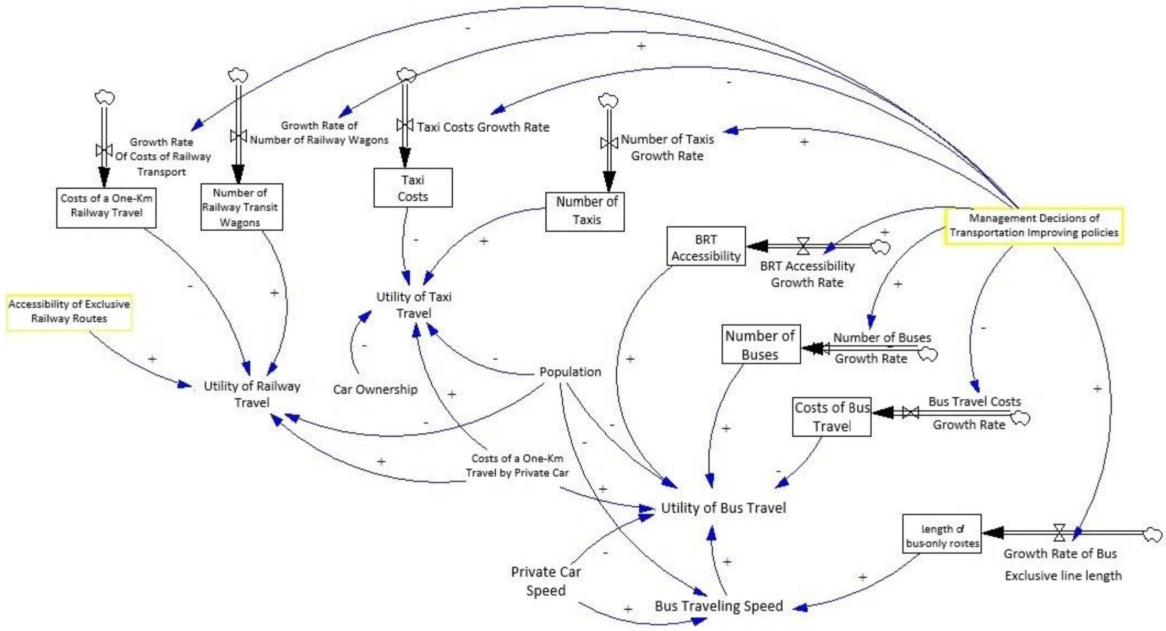


Fig. 5. Causal diagram of TDM policies and transportation modes utility

The convenience of a taxi trip, as shown in the figure 5, is affected by the variables of the number of taxi cars, the taxi charges, the cost of one kilometre of private car travel, the ownership of the car and the population. The cost of taxiing and the number of taxi cars vary according to a specific growth rate. In this model, in addition to the management decisions of the private car transportation pricing policy, the management decisions of the public transport policy are also considered, which varies according to different demand management policies.

By increasing these decisions, the growth rate of the number of taxies will increase and the growth rate of taxi costs will decrease. The utility of bus trips is also influenced by variables such as bus speed, private car transport speed, number of buses, accessibility of BRT lines, travel costs by bus, cost per kilometre of private car travel and population. The cost of traveling by bus, the number of buses and accessibility of BRT lines also vary with a certain growth rate. In this case, with the increase in management decisions for the policy of improving public transportation, the growth rate of travel costs is reduced and the growth rate of the number of equipment and accessibility to BRT lines increase.

The speed of travel by bus also comes from the variables of private car transport speed, population and length of bus exclusive lines. The length of the bus exclusive lines also increases with a certain growth rate based on the management decisions of the public transport policies. The utility of rail travel is also influenced by the availability of general railways accessibility options, the cost of one kilometre of public rail travel, the cost of a one-kilometre private car travel, the total number of public rail transport wagons and the population. The cost of a one-kilometre rail travel and the number of public rail freight wagons vary with a certain growth rate according to management decisions.

5. Mathematical Equations of the Model:

Based on the conceptual relationships of the variables, mathematical relations are obtained between them. Some of these relationships were derived directly from definitions of variables, and in other cases, mathematical relations between variables were logically assumed to dominate a mathematical relationship. The mathematical relations presented in this study are based on logical relationships, regressions on results of simulations, relationships presented in the past studies and available information from Isfahan municipality, (Habibian and Kermanshah 2013; Haghshenas et al. 2015; Mansoori et al. 2016). Variable descriptions are showed in table 1, mathematical relations used are as table

2, and regressions are as figure 6.

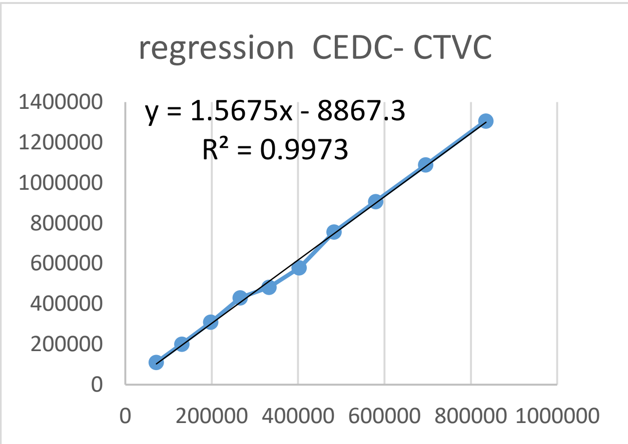
Table 1. Definitions of Variables

Symbol	Description	Symbol	Description
AREA	Area of CBD	PARP	Parking price in CBD per hour
BACK	Bus passenger-km cost	PARR	Parking price in CBD annual growth rate
BACR	Bus passenger-km cost annual growth rate	PCCK	Private car passenger-km cost
BALC	Bus exclusive line length per capita	PCOC	Private cost operating cost per km
BALR	Bus exclusive line length annual growth rate	PCAC	Private car average occupancy
BASP	Bus average speed in CBD	PCSP	Private car average speed in CBD
BAVC	Bus vehicle number per capita	PCTD	Private car travel demand of CBD
BAVR	Bus vehicle number annual growth rate	PCTU	Private car travel Utility
BIKF	Bike facilities per capita	POPC	Population of city
BUTD	Bus travel demand of CBD	POPR	Population annual growth rate
BUTU	Bus travel Utility	RACK	Rail passenger-km cost
CARC	Car Ownership per capita	RANL	Rail network length in CBD
CARR	Car ownership annual growth rate	RAOP	Rail system operates in city (0 , 1)
CCAR	Car ownership to CBD per capita	RATD	Rail travel demand of CBD
CEDC	Car equivalent demand of CBD	RATU	Rail travel Utility
CORP	Cordon pricing price	RAWC	Rail wagon number per capita
CTDC	Travel demand of CBD	RODP	Road length per capita
CTDP	Percentage of the trips to CBD	TRMO	Traffic Mobility indicators
CTVC	Total Traffic Volume of CBD	TTDC	Total travel demand of city
EMIS	Emission indicators	TTDI	Average Trip Distance
EMPC	Employment per capita	TXCK	Taxi passenger-km cost
ENRG	Energy Consumption indicators	TXKR	Taxi passenger-km cost annual growth rate
NTTD	Non-motorized travel demand of CBD	TXCC	Taxi number per capita
NTTU	Non-motorized travel Utility	TXCR	Taxi number annual growth rate
ODEV	Odd – Even policy implementation (0 , 1)	TXTD	Taxi travel demand of CBD
PARE	Parking space in CBD per employment	TXTU	Taxi travel Utility
PARH	Parking duration in hour		

Table 2. Systematic Relationships

Equations	Estimation Method
$POPC = \int \mathrm{POPR}\,\mathrm{dt}$	Logical relation
$CARC = \int \mathrm{CARR}\,\mathrm{dt}$	Logical relation
$BACK = \int \mathrm{BACR}\,\mathrm{dt}$	Logical relation
$BALC = \int \mathrm{BALR}\,\mathrm{dt}$	Logical relation
$BAVC = \int \mathrm{BAVR}\,\mathrm{dt}$	Logical relation
$TXCC = \int \mathrm{TXCR}\,\mathrm{dt}$	Logical relation
$TXCK = \int \mathrm{TXKR}\,\mathrm{dt}$	Logical relation
$.\mathrm{CARR} = 0.02 - (0.02 \times \mathrm{CARO}) + (0.115 \times \mathrm{ODEV} \times \mathrm{CTDP})$	(Haghshenas et al. 2015) & predict odd-even impact
$\mathrm{TTDC} = POPC \times (0.63 + (2.62 \times CARO) + (0.2 \times \mathrm{EMPC}))$	(Haghshenas et al. 2015) & (Isfahan 2016)
CCAR = (1 – (0.25* ODEV)) ×CARC	(Isfahan 2016)
$\mathrm{CTDC} = \mathrm{TTDC} \times \mathrm{CTDP}$	Logical relation
$.\mathrm{PCTD} = \mathrm{CTDC} \times (\mathrm{EXP(PCTU)} / (\mathrm{EXP(PCTU)} + (\mathrm{EXP(TXTU)} + (\mathrm{EXP(BATU)} + (\mathrm{EXP(RATU)} \times \mathrm{RAOP} + (\mathrm{EXP(NTTU)})$ Similar in (TXTD, BUTD, RATD, NTTD)	Aggregate Multi Nominal Logit
$\mathrm{PCTU} = (-1322 \times \frac{\mathrm{PCCK}}{\mathrm{GDPP}} + 0.02 \times \mathrm{PCSP} + 2.08 \times \mathrm{CARC} + 0.84 \times \mathrm{PARE} + 50 \times \mathrm{RODP})$	(Haghshenas et al. 2015)

$TXTU = (26.96 \times \frac{TXCA}{CARC} - 6.12 \times \frac{TXCK}{PCCK})$	(Haghshenas et al. 2015)
$.BATU = -1.65 \times \frac{BACK}{PCCK} + 150.7 \times BAVC + 1.23 \times \frac{BASP}{PCSP})$	(Haghshenas et al. 2015)
$NTTU = (1.42 - 0.04 \times TTDI + 1.62 \times BIKF)$	(Haghshenas et al. 2015)
$.RATU = (-1.82 \times \frac{RACK}{PCCK} + 820.2 \times RAWC + 0.06 \times \frac{RANL}{AREA})$	(Haghshenas et al. 2015)
$BASP = 0.54 \times PCSP + 64.2 \times BALC$	(Haghshenas et al. 2015)
. PCCK=(PCOC+(PARP× PARH + CORP)/TTDI)/PCOC	Logical relation
$.CEDC = \frac{PCTD}{PCOC} + 2 \times \frac{TXTD}{TXOC} + 5 \times \frac{BATD}{BAOC}$	Logical relation
$CTVC = -8867 + 1.567 \times CEDC$	Regrissoion in results of simolation
$PCSP = 55.136 \times EXP(-0.000002 \times CTVC)$	Regrissoion in results of simolation
AREA; BACR; BALR; BAVR; BIKF; CARR; CORP; CTDP; EMPC; ODEV; PARE; PARH; PARR; PCOP; PCOC; POPR; RACK; RANL; RAOP; RODP; TTDI; TXKR; TXTU	Model Inputs
TRMO = PCSP/ AFSP $EMIS = 0.076 \times CTVC \times TTD$ $ENRG = 0.154 \times CTVC \times TTDI$	Model Outputs



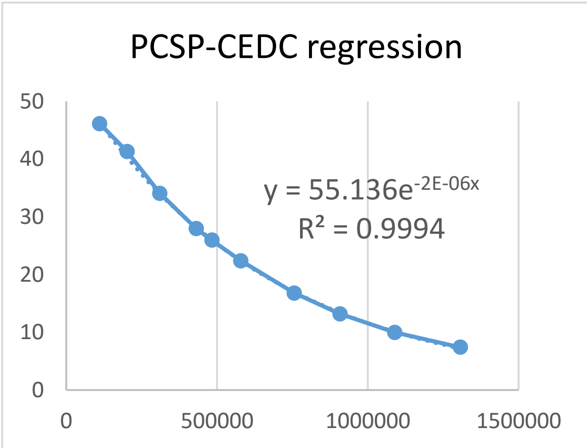


Fig. 6. Regressions in Results of Simulations

6. Transportation Demand management policies modelling:

The study examines the policies of BRT network development, improving the taxi services, cordon pricing, increasing parking prices, completing metro network development, improving bicycle facilities, improving the bus services, encouraging to carpool, and odd-even policy. Along with that, the policy of continuing the current situation is also considered as a baseline for comparing the results of policies. The method for applying the policies into Vensim software for the next ten years is described below. The information needed for policymaking is obtained from the Department of Transport Studies of the Municipality of this city (Isfahan Municipality 2016).

6.1. Bus services improvement

In the present situation, about 30 buses are being added to the fleets in the central area of the Isfahan city annually. In the policy of improving the bus services, instead of 30 devices, about 60 buses will be added to the fleet annually.

Since the model runs for ten years from 2015 to 2025, during this period, about 600 buses will be added to the number of bus units in the area.

Also the city bus fare is now an average of 3000 IR rials[1]. In Iran, 20% is added annually to the bus ticket price. But in line with the policy of improving the busy system and the impact of the variable policy decisions of the public transport policy, this amount would be 10%.

6.2. Improvement of Bus services and BRT network development

As explained, in the current situation, about 30 buses are being added to fleets in the central area of the city of Isfahan annually. In this policy, instead of 30 devices, about 60 buses will be added to the fleet annually. The length of the BRT routes and the bus exclusive lines in the policy of continuing the current situation, according to available resources, is increased annually by about 1400 meters. Now in the policy of improving bus services, about 2,000 meters will be added to these routes.

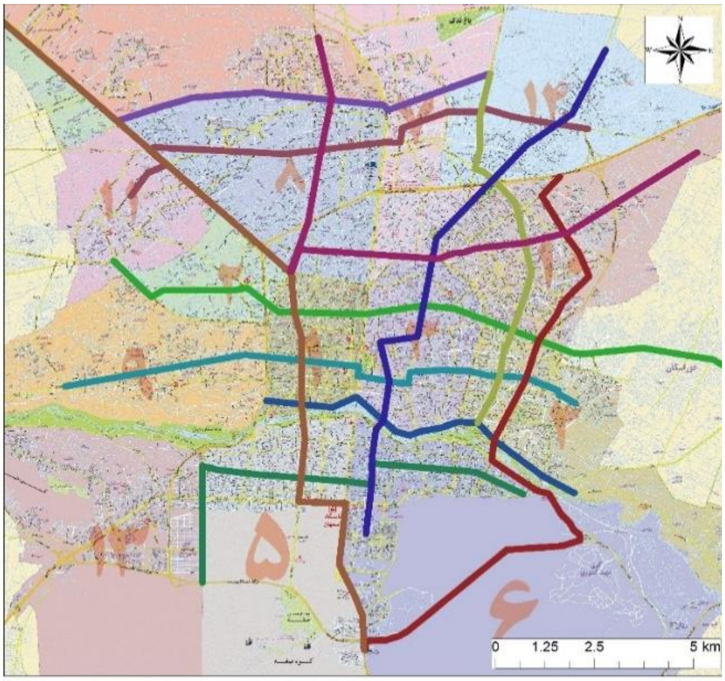


Fig. 7. the locations of BRT line in Isfahan city

6.3. Taxi services improvement

In the current situation, about 500 taxi vehicles are added to the taxi fleets every year. In the policy of improving taxi services, about 900 taxis will be added to the taxi fleets every year. Taxi fare in Isfahan is now an average of 5000 IR rials for Passenger-Km. The trend is to increase the price of fares by 20% every year but in accordance with the policy of improving taxi services, it will be reduced to 10%.

6.4. Cordon Pricing Policy

There is no cordon pricing policy running in Isfahan city, but in line with the implementation of this policy, a fare of 30,000 IR rials will be assigned in accordance with previous studies about cordon pricing in this city. There is also an

[1] Each $US used to be equal to 43500 IR rials in year 2015

annual growth rate of 15% for this input.

6.5. Parking pricing policy

In the policy of increasing parking prices, the hourly price of parking in the central area of the city will increase to 5000 IR rials[2], which is 3000 IR rials in the current situation. The annual growth rate which is 20% in the current situation will be set to 25% in line with policy of increasing parking prices.

6.6. Improving Bicycle Facilities

In the policy of improving bicycle facilities, according to available resources, the amount of variable bicycle facilities will increase by 0.01 per year (Isfahan Municipality 2016).

6.7. Metro Network Development

In the year under study in Isfahan, there is no metro network servicing. Therefore, in the model under consideration, by assuming zero for the variable of the existing rail system, the system is excluded from the model.

Fig. 8. the future plan for metro lines in Isfahan

6.8. Encouraging to Carpool

With the policy of encouraging to carpool, the passenger coefficient rises from 1.5 to 1.87 (Isfahan Municipality 2016). In the set of travel demand management methods, carpooling is one of the ways to reduce demand, or actually to reduce vehicle-km.

6.9. Even-Odd Restrictions Policy

In the even-odd traffic restriction policy, vehicle ownership in the central area is initially reduced by 25% (Isfahan Municipality 2016). But over time, due to the fact that with the even-odd traffic restriction policy and the individual's desire to buy a car and having cars with both even and odd plaques, the percentage of trips to the central area of the city will be affected, as well as car ownership in the area. Input variables which change in each TDM policy are

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[2] Each $US used to be equal to 43500 IR rials in year 2015

presented in table 3:

Table 3. Input Variables

TDM Policy	Input Variables
Bus services improvement	BACR; BAVR
Improvement of Bus services and BRT network development	BACR; BALR; BAVR
Taxi services improvement	TXKR; TXCR
Cordon Pricing	CORP
Parking pricing	PARR
Improving Bicycle Facilities	BIKF
Metro network development	RAOP
Encouraging to Carpool	PCOC
Even-Odd Restrictions	ODEV

7. Results of evaluating demand management policies

Output indicators for evaluating the policies in this model include air pollution (in kilograms), energy consumption (in liters), and traffic psychology. For example, the variation of the indicator of air pollution for the past ten years is given in figure 9.

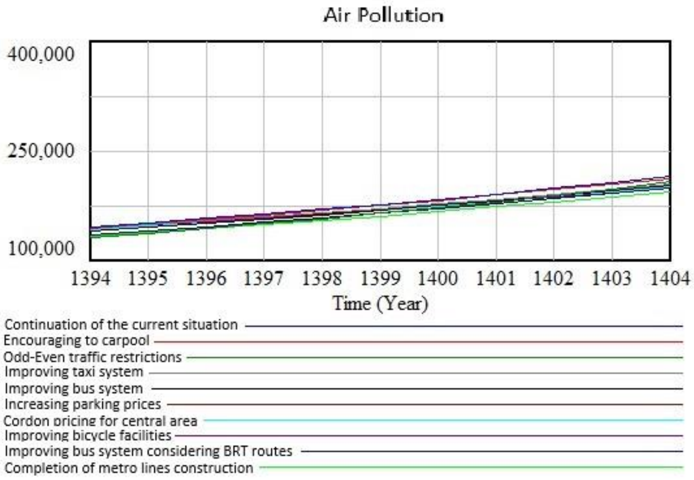

Fig. 9. Variation of the indicator of air pollution

The predicted values of these three indicators are shown in table 1 for all policies in year 2025. The traffic flow indicator for each policy is divided into the highest value of the indicator among the policies. Note that the higher the traffic flow indicator, the better the policy is. For the two indicators of air pollution and energy consumption, the less they are, the better the policy is. The value of these two indicators in year 2025 is divided into the highest indicator of the policy, which is the policy of the continuation of the existing situation. The result is a dimensionless number which is between 0 and 1. Finally, by obtaining dimensionless numbers between zero and one, based on these three indicators a comparison will be made to evaluate the policies. The values of output indicators in year 2025 and the rating of policies.

Table 4. The values of output indicators in year 2025 and the rating of policies

Indicator \ Policy		Continuation of current situation	Metro network development	Improving bus services considering BRT lines	Improving bicycle facilities	Cordon pricing for central area	Increasing parking prices	Improving bus services	Improving taxi services	Odd-even restrictions	Encouraging to carpool
Air pollution		213318	195448	199976	200823	202344	203881	204335	205615	208344	211418
	Normalized Value	0.083	0.063	0.059	0.052	0.044	0.042	0.036	0.023	0.009	
Energy consumption		426636	390896	399951	401646	404687	407761	408671	411230	416687	422836
	Normalized Value	0.083	0.063	0.059	0.052	0.044	0.042	0.036	0.023	0.009	
Traffic flow		0.433	0.517	0.501	0.493	0.389	0.473	0.466	0.457	0.446	0.438
	Normalized Value	1	0.969	0.954	0.946	0.915	0.902	0.884	0.862	0.847	

The rating of each policy is calculated from the sum of the normalized indicators with equal weights. The final result will be in the form of table 5 and the following graph (figure 10).

Table 5. Raking of policies, based on the scores

policy	Metro network development	Improving bus services considering BRT lines	Improving bicycle facilities	Cordon pricing for central area	Increasing parking prices	Improving bus services	Improving taxi services	Odd-even restrictions	Encouraging to carpool
Sum of scores	1.166	1.096	1.072	1.050	1.003	0.986	0.956	0.908	0.865
Rank of policy	1	2	4	3	5	6	7	8	9

In accordance with table 5, in the central area of Isfahan, the policy of improving metro public transportation system and improving the bus services, including BRT, are the most influential policies in the future. The reason for this is the lack of completion of metro network development as well as bus exclusive lines in Isfahan. Also, since the rail transport system does not produce air pollution, the rate of air pollution reduction and energy consumption in this policy is more evident than other policies.

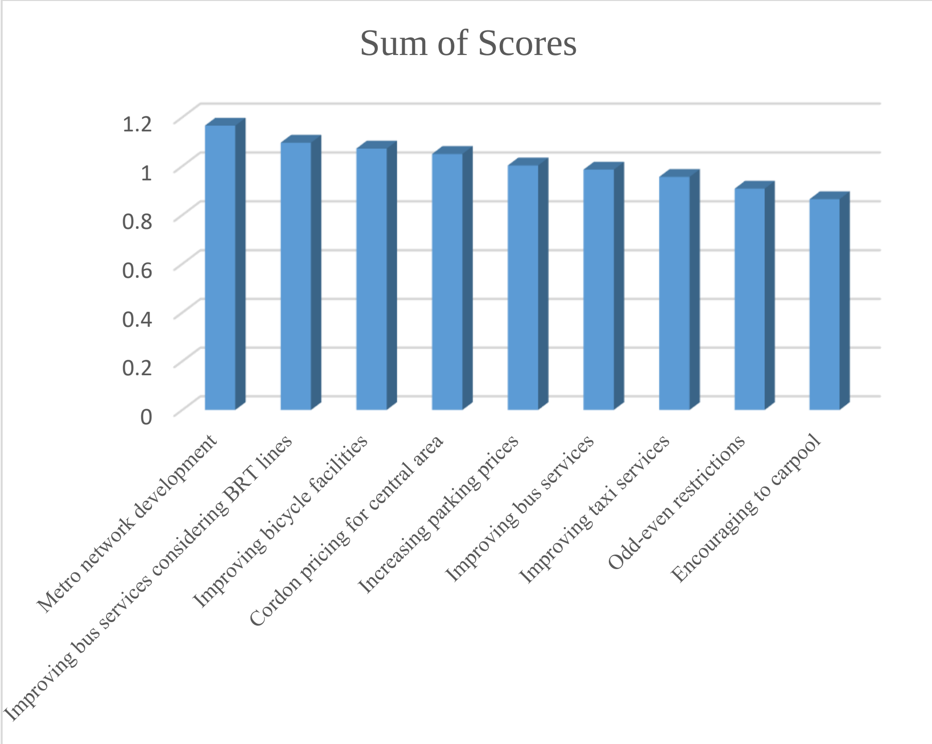

Fig. 10. Policies Scores

Among the restrictive policies, cordon pricing of the central area is the most effective policy but the policy of odd-even traffic restrictions does not have much effect, and the reason is that over time, the willingness of people to buy a car to have cars with both odd and even plaques will be further increased. Therefore, the policy of completing metro network development is the most effective policy in this study. It's also worth mentioning that the completion of metro network development is costly and other policies can somewhat bring about the results of this policy.

According to the results, in the share of transportation modes, the share of private car has decreased in line with the ranking of policies. In enhancing the share of the bus, BRT network development, as well as improving the system excluding BRT is the most effective policy. Also for increasing the share of taxi, improving taxi services is the most effective policy. The share of buses and taxis in the policy of improving bicycle facilities is low, and the reason is that a higher percentage of trips is accrued to non-motorized transportation in this policy in comparison with the other policies. Also the share of bus and taxi in the policy of metro network development is low, and the reason is 9% of the total trips is dedicated to rail transportation. Given that the characteristics of each policy have somehow targeted some of the goals of the travel, the application of several travel demand management policies simultaneously can cover more travels and the effects can be more than the application of individual policies. Also, in some cases, the implementation of effective policies faces problems cause by legal reasons or the general interests of people. This is a problem that can be solved by applying mixed policies or policy packages. In this study, some restrictive policies are combined with more effective encouraging policies in order to evaluate the effects of the simultaneous applications of two types of policies in the form of a policy package. Scoring for policies is also done in the same way as previously mentioned. The results are presented in Table 6.

Table 6. The value of output indicators in 2025 and the ranking of combined policies

Policy / Indicator		Continuation of the current situation	Completion of metro network development+ cordon pricing for central area	Improving bus services including BRT lines + codon pricing for central area	Completion of metro network development + odd-even restrictions	Improving bus services including BRT lines + odd-even restrictions	Encouraging to carpool + cordon pricing for central area
Air pollution		213318	184474	189002	190476	195100	200444
		Normalized Value	0.135	0.114	0.107	0.086	0.060
Energy consumption		426636	368948	378004	380952	390200	400887
		Normalized Value	0.135	0.114	0.107	0.086	0.060
Traffic flow		0.433	0.573	0.557	0.530	0.519	0.494
		Normalized Value	1	0.972	0.924	0.906	0.862

As expected, the impact of combined policies on reducing air pollution and energy consumption and increasing traffic flow is more than the effect of a single policy. So that, except the package “encouraging to carpool + cordon pricing for central area”, all other combined packages were more effective than a single policy. In the end, to obtain the score of any combination of policies, similar to the previous process, the numbers obtained from the three indicators for each policy are added together. Finally, the policies are ranked according to the normalized numbers. The final results will be as presented in table 7. The combined policy of " metro network development + cordon pricing for the central area" has been the most effective policy.

Table 7. Ranking of combined policies, based on the scores

Policy	Completion of metro network development + cordon pricing for central area	Improving bus services including BRT lines + codon pricing for central area	Completion of metro network development + odd-even restrictions	Improving bus services including BRT lines + odd-even restrictions	Encouraging to carpool + cordon pricing for central area
Sum of scores	1.270	1.200	1.138	1.078	0.982
Rank of policy	1	2	3	4	5

8. Conclusion:

This study uses a system dynamics analysis to investigate the effect of nine policies on the indicators of air pollution, energy consumption, traffic flow, and share of different transportation modes from total trips in the central business district of Isfahan. These policies are policy of BRT network development, improving the taxi services, cordon pricing for the central area of the city, increasing parking costs, metro network development, improving bicycle facilities, improving the bus services, encouraging to carpool and the odd-even traffic restrictions and their combination. For the city under study, results show that among single policies, policy of completing metro network development, BRT network and bus services development, improving bicycle facilities, cordon pricing for the central area, increasing parking costs, improving bus services, improving taxi services, odd-even traffic restrictions, and encouraging to carpool are the most effective policies respectively. In the share of transportation modes, according to the results, the share of private car decreased in line with the rating of the policies. In enhancing the share of the bus, BRT network development is the most effective policy, as well as improving the bus services excluding BRT. Improving taxi services is the most effective policy for increasing the share of taxi. The share of buses and taxis is low in the policy of improving bicycle facilities, and the reason is that a high percentage of trips is accrued to non-motorized transportation, in this policy in comparison with other policies. Also the share of bus and taxi in the policy of metro network development is low, and the reason is 9% of the total trips is dedicated to rail transportation. In applying combined policies, there was more impact on reducing air pollution and energy consumption and increasing traffic flow in comparison with applying individual policies.

Among combined transportation demand management combined policies, “Completion of metro network development + cordon pricing for central area”, “Improving bus services including BRT lines + codon pricing for central area”, “Completion of metro network development + odd-even traffic restrictions”, and “Encouraging to carpool + cordon pricing for central area” are the most effective policies, respectively. Assessing different demand management policies with different indicators are the limitations of conventional transportation planning procedures and SP interviews with citizens. The most important result of this research is to provide a superior method for evaluating demand management policies that can help municipal managers and city policymakers with decision making and implementation of demand management policies. The proposed method in the macro-scale assessment of demand management methods, without addressing the spatial details and issues of the various traffic areas of the city, determines the general impacts of each policy on changing different indicators such as traffic flow of the streets, air pollution, energy consumption, and share of private car in the central business district of Isfahan. The presented method can be used for transportation policy-making and assessment of different policies with different indicators in other cities of the world.

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