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Fuel Consumption Monitoring for Travel Demand Modeling

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Abstract

The purpose of this research is to investigate the impact of fuel consumption patterns on travel demand estimation. This paper evaluates and calibrates travel demand estimation by CUBE software and its relation to fuel consumption, with use of data provided by Sharif University, for the city of Shiraz, Iran in 1999. This research proves the presence strong correlations between vehicle fuel use and the trip's generation process by exogenous and endogenous variables. The effect of energy consumption patterns on generation and distribution stage of travel demand modeling based on inverse ability has been considered in the present model.

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Keywords: Fuel consumption, Travel Demand Modeling, Trip Generation, Trip Attraction, TAZs, TADs

1. Introduction

World oil demand is projected to increase larger than 40% by 2030, which is mainly from Asian countries like China and India, where transportation industries are rapidly expanding. Transportation accounts for almost 20% of the world’s energy consumption and more than 50% of the consumption of liquid fuels. In the year 2030, the transportation sector alone will consume the same amount of liquid fuel as that consumed by all sectors in 2003; this fact necessitates the development of the travel demand modeling based on fuel consumption.

Transportation is a needed life system because movement of goods and services (products) is similar to the blood circulation process and just in the same way that any vascular problem will reduce physical abilities of the human body, any problem with transportation will compromise capabilities of organizations and economic systems of nations.

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Furthermore, in the transportation sector, energy or fuel acts as food like in a human's body, so it's quite clear that healthy life and ability are impossible without it. Development of transportation has many aspects as it paves the way for progress of organizations and prosperity of any economy. Inefficient use of transportation will lead to consumerism, environmental pollution, economic losses in the form to time, and capital waste. Evolution of the complex industry of transportation should be studied in parallel to history of human civilization, including social, economic, technological developments and changes in lifestyle. The transportation sector consumes about 50%of oil demand in the world and is considered as an important sector for incremental oil demand in the future.

The vehicle ownership(intensity), efficiency of vehicles, public transportation, transport infrastructure, per capita income, cost of vehicle use and fuel price are among the factors which are shaping the trend of oil demand in this very important sector, and road transportation contributes more than 80% of oil demand in the transportation sector. The economic impact of such congestion can be substantial. Not only does congestion have an impact on economic development, but it also exacerbates bad air quality and created the energy consumption problems. These are as well the most rapidly growing sources of greenhouse-gas emissions, including carbon dioxide, chlorofluorocarbons, nitrous oxide, and carbon monoxide in the region. With road infrastructure continually lagging behind the growth in vehicle's numbers on the road, speeds in urban areas have consistently dropped, especially in the city centers. Lower travel speeds, frequent stops and starts, produce finer fuel consumption, and greater emissions of noxious substances than freely flowing traffic. This research tried to deliver a brief review on the Travel demand and fuel consumption of transportation in Iran, and the fast-paced growth-based demand of energy consumption in this sector.

Eva Ericsson and Hanna Larsson completed more researches about optimizing fuel consumption based on transportation aspects in the city of Lund, Sweden, in last decade. First-step in transport facility management are finding relevant parameters for describing driving patterns. An experimental study was carried out to compare driving patterns between and within different street-types, drivers and traffic conditions. The knowledge attained in Ericsson and Bratt (1999) study may be a step towards a better knowledge of driving patterns and their variation, and may provide possibilities of changing driving patterns and thus exhaust emissions from vehicles. Knowledge about driving patterns is also an essential part in efforts to improve models to calculate emission from traffic in urban environment (Ericsson, 2000).

In the 70s, several studies described the connection between driving patterns and fuel consumption and exhaust emissions. Most of these studies were aiming at constructing typical driving cycles for test procedures of new vehicles, (Watson, 1978). In a large-scale, study (Andre et al., 1995) made it possible to derive average driving cycles for driving in European countries. A large number of driving patterns registered in real traffic have been collected; however, the analyses are descriptive without any attempts to explain why driving patterns vary in certain characteristic ways.

The variation in driving patterns may be influenced by several factors, for instance, the external conditions such as street type, number of lanes, traffic conditions, the type of car, etc., but also by characteristics of the driver. Kenworthy (1986) and Lyons et al. (1989) found that driving patterns are connected with urban structure and local environment as well as time of day. Rosqvist (1998) studied residential areas and found that fuel consumption and exhaust emission were highly dependent on street design and the structure of the street net.

Earlier studies describe average driving patterns divided on motorways, highways and urban streets, e.g. Andre (1998), and not many studies have investigated differences in driving patterns among street types within urban areas. Average speed has been investigated in connection with different road categories In the Germany and the Switzerland (Hassel et al., 1993). Average speed is a comprehensive description of driving patterns while for more detailed analysis, complementary parameters will be needed to describe different characteristics of driving patterns (Gurnsler, 1993). Weijer (1997) has earlier addressed various parameters describing driving patterns. The gender variable thus showed several interaction effects of the street type variable. Assuming that gender is one of the several possible subdivisions of drivers this result states that different driver types behave differently due to changes in the street environment. This result may have the impact on street design and traffic planning. It emphasizes the importance of having a representative sample of drivers to be able to evaluate the effect of measures taken in the traffic environment.

Assessment of the demand for transportation fuels interests many researchers and policy-makers that are considering various energy plans. Estimation of the demand for gasoline, diesel fuel, CNG fuel, and jet fuels using the historical trends analysis approach is convenient and popular among researchers.

In Europe, this approach is used to produce estimates of the price and income elasticity of demand for these three fuels for Individual European countries (Mark, 1979). Also, transport activities, energy consumption, and carbon dioxide emissions from transportation are projected for the 10 countries of Central and Eastern Europe (Zachariadis and Kouvaritakis, 2003). Another effort focused on the fuel economy of passenger cars and light trucks, a long-disputed issue with serious implications for the worldwide energy use (Zachariadis, 2006). This study tried to use the fuel consumption data for future forecasting of all trip generation items that depend on fuel consumption and also used these methods for fuel consumption estimation.

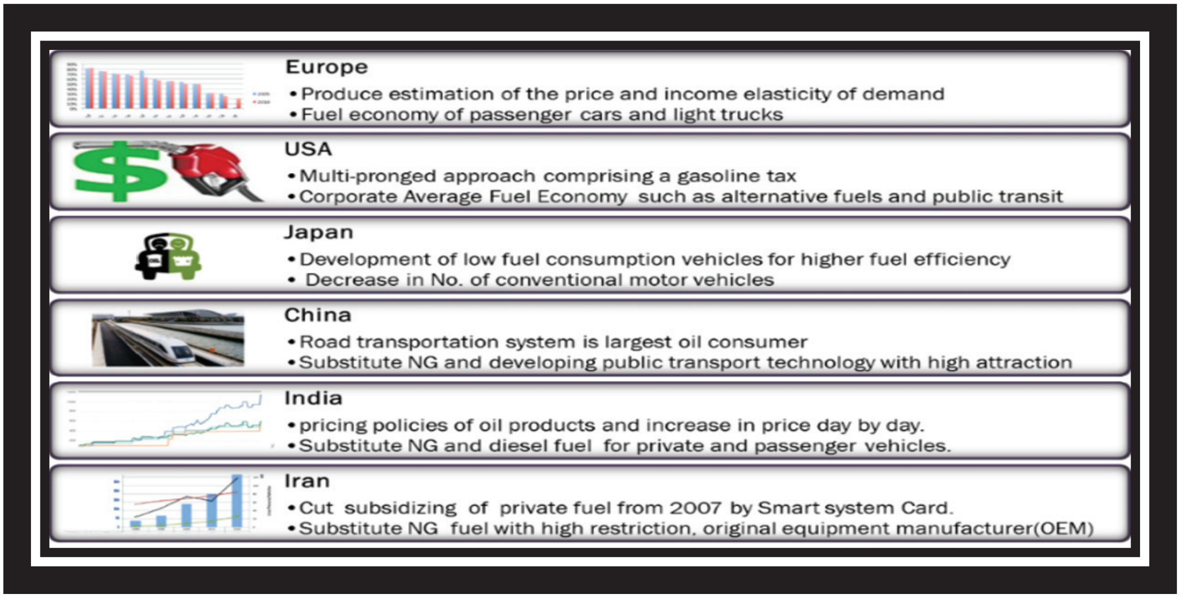

Fig. 1. Various policies by different nations about control of fuel consumption.

In the various nations, different financial, technological and transportation policies adopted to significantly reduce the enormous amount of gasoline consumption, which can be seen in Fig.1. The brief description collected from Silva et al. (2009), Jakopong et al. (2010), Jafari and Baratimalayerei (2008), Verdinejad (2009), Arentze and Timmermans (2004), Bates (2000), Bhat (2004), Foumunung et al. (1999) can be seen in Fig.1.

All the above mentioned facts have turned gasoline consumption into a crisis in Iran. Unfortunately, the present energy conservation strategies, including standards, developing alternative fuel (CNG/LPG), technical inspection, and excluding old vehicles have not reduced consumption efficiently. The proposed solutions, which are categorized into short-term (such as increasing buses, restriction of trips to central regions of major cities, registration policy-making, etc.), mid-term (such as increasing production capacity of refineries, justifying and goal-orienting subsidies, increasing fuel prices to international levels, etc.) and long-term (developing rail-transportation systems, etc.) solutions, are essential steps for transportation energy consumption providence.

The purpose of this research is to use fuel consumption data, and other related records, to model travel demand conditions. The vision behind this research can be understood by this statement; “how to establish four steps classic transportation models by records from transport fleet consumption’s data." Absolute results or answers for this question also solve more problems in different areas as economic aspects, environmental aspects, decision making, fuel demand, future forecasting, etc. Also, these actions help planners to forecast and plan with real and factual situation data. Efforts for answering this question can be effective to conquer the present difficulties in different economic, environmental, decision making, fuel demand, future forecasting aspects and etc. to reach the suitable sustainable development in transportation. Furthermore, these efforts can be helpful for planners to identify reliable data and exploring the alternative methods for travel demand modeling.

The main objective of present study is to create the accurate correlation between fuel consumption and travel demand modeling. Unfortunately, there are not enough studies considering Iran's fuel consumption, concerning the reviewed papers. Given the current circumstances, the crisis in energy consumption makes a comprehensive evaluation appears more evident.

Three outcomes can be used to estimate consumer behavior over short time horizons: gasoline consumption, vehicle miles traveled (VMT), and vehicles fuel economy (MPG). Gasoline consumption and VMT represent the intensive margin, and MPG represents the extensive margin. Dissecting the intensive and extensive margins, will help us to find a significant differential effect in household MPG, especially among newer vehicles. The structure of the present paper is as follows: The research is organized into 6 sections. A brief introduction to the topic and scope of the work has been presented in section 1. Section 2 explains Methodology, and after is given the data result in section 3. This research will reach the conclusion in section 4, acknowledgment part in section 5 and lastly references to the materials are given in section 6.

2. Proposed Method and Methodology

The modelling structure will be similar to the traditional four-stage Travel Demand Forecast Model (TDFM) for the requirements of this study area. Traffic Analysis Zones (TAZs) contains 15 internal zones and 8 external zones, but Traffic Analysis Districts (TADs) contain 157 internal zones. Demography observation and trip's survey were estimated with data from the Shiraz city; center of Fars province, Iran country, 1999 Sharif university data, and travel observation data has been collected (2009).

Each individual TAZ is divided to about 10 districts based on road's boundaries, which has the close equivalency factor for contained districts. All the statistics and demographic data controlled and tested as well as both zonal layers. The main advantage of this method is that it can provide the opportunity to consider more concentrated centroids compared to just 15 centroids in TAZs, furthermore, implementing this type of model, precise identification of different zonal applications (residential, industrial, public and private) can be easily feasible. On the other hand, one of the evident disadvantages of this type of modeling is that considering the excessive number of attributes can cause increasing the time, effort and money.

This model is essentially a conventional four-stage model with a number of additional sub models. Fuel price and socio-economic conditions affect trip generation. Fuel consumption shows the passing distance to reach a location and intensity of the activity, and socio-economic factors determine the magnitude and extent of population activity. Author developed transportation networks via ArcGIS9.2 & ArcGIS9.3 software and travel demand models are developed by using CUBE5 and TransCAD4.5 transportation planning software packages in GIS platform. All these software packages are implemented at the Transportation System Engineering (TSE) laboratory with the license purchased by the Indian Institute of Technology Bombay. The methodology used for planning travel demand model and its application for evaluating appropriate land use and sustainability of the model can be explained in following steps:

1. Generation and Creation of network for case study and define all necessary attributes.
2. Define all characteristics and attribute of network for travel demand model generation.
3. Generation and Validation of base year OD Matrices.
4. Development and Calibration of Travel Demand Model.
5. Model Application.
6. Fuel Indices and Evaluation of Alternatives.

2.1. Base year OD matrix generation

This process starts with the last 15 years Home Interview Survey (HIS) data as input. HIS obtained sample size magnitude equal to 4.3% of the number of households, i.e. to select one sample out of 23 households(literature standards mentioned that for more than 1 million population cities, it could be more than 4%sample size magnitude). According to that survey, 1,142,282 population of Shiraz's city had 1,769,240 trips per day that is the equal 1.55 trip rate (trip/person), but planner prefer to use the correction factor to match and fix this data with cordon line and screen line survey. So after correction total trips were equal 1,918,321 that we can obtain 1.68 trip rates. (Correction factor was 1.08, according to standards use of the correction factor should be less than 10% for an idealistic survey)The matrices are loaded on to the network, and the assigned values are compared with the ground counts to validate the Matrices. The data related to 1999s HIS was defined as base year data, however, because of structural alterations in urban texture, applying the growth factor is not the accurate way for validating current model in present condition, instead for providing the updated OD matrix reconsideration of trip rate versus population and urban alteration, backward analysis with traffic counting statistics in cordon line and screen line and applying of innovative methods like mobile location statistical data.

2.2. Travel demand model development

- Planning variables based on TAZs by old zonal system as per 1999 study (15 internal zones) are available.
- New zonal system which has call TADs contains 157 internal zones and 7 external zones.
- Equivalencies between old and new zonal systems are established.
- Based on old zonal system, increments of population in each zone are found and the aggregated population is apportioned based on the proportions obtained.
- Using the planning variables and validated total O-D matrix for base year (1998), the revised skims obtained after successive modal split and traffic assignments will be used to calibrate the gravity model.
- The model is mainly based on the transport system attributes. The cost skims obtained from the assignment are used to calibrate the mode choice model.
- The Public transport matrix includes the person trips performed by Public Transport (Bus, Taxi and Metro), while the Private vehicle matrix includes person trips by car and two-wheeler. But in this project just considering private vehicle matrix because not coding public transport network yet. The public transport assignment is also required to assign the trips as per the observed modal shares. After performing the public transport assignment, the assigned flows across the screen lines are compared with the observed flows.
- The private vehicle passenger matrices are converted into peak hour PCU units (Passenger Car Unit, a metric used in Transportation Engineering)

The regional Travel Demand Forecast Model (TDFM) quantifies the amount of travel expected to take place on the transportation system. The results are used to estimate the impacts of constructing new or improved highways, or implementing alternative transportation services or demand management activities. The TDFM is capable of estimating the number of vehicles on regional freeways; the vehicle distance travelled, and highway delays. This information is used in the planning process to support decision-makers in selecting transportation plan alternatives, policies, and programs. In addition, the results are used to provide detailed information, such as traffic volumes, to state, regional, and local engineers and planners for use in facility design. The TDFM is calibrated based on data collected in the 1999 by Sharif's research institute. The surveys recorded the number of trips made, trip purpose, origin and destination.

2.3. Travel demand process

Early trip generation models were commonly developed by regression analysis because of its power and simplicity. The independent variables in such models were usually zonal averages of the various factors of influence. Trip generation equations developed by regression are still used by some planning agencies, more commonly for attraction models than for production models. This is because only zonal averages of trip attracting characteristics are usually available since most travel surveys do not survey at trip destinations. Obtaining more detailed data for individual attraction zones require a survey of trip attractors, such as a workplace survey. It may be possible to calibrate and monitor this evaluation by fuel consumption data and chain distance survey. Trip distribution determines the travel volumes between TAZs. This decision must consider both the relative attractiveness and accessibility of all possible destinations in the model area. A gravity model is used to represent this choice for all trip purposes, except external/external trips where a growth factor model is used. The gravity model is designed based on the observation that traffic flow decreases as a function of the distance between TAZs. Separate gravity models are developed for each trip purpose, as different trip purposes exhibit different distribution characteristics. For example, people will travel much further to work than to go shopping. Mode choice determines, which motorized mode vehicle or transit travelers will use. The mode choice component of the TDFM uses a multi-nominal logit model. The stated model was developed based on 1999 survey. The assignment model uses a multi-user simultaneous equilibrium assignment algorithm. In equilibrium, all travelers are assigned to their optimal path; no traveler can have a shorter path available.

2.4. Network improvements

Descriptions of the urban network provide information on the "supply" of transportation. This information on infrastructure and services is used in estimating urban activity, as well as determining where people will go and what mode they will use to get there. The TDFM uses detailed estimates of highway infrastructure, including information on over-all roadway segments, such as location, length, number of lanes, functional classification, and area type. For the functional classification, the TDFM uses the freeway, principal arterial, minor arterial, collector, local, and others basic ramp classes. For the area type, the TDFM uses urban business, urban, suburban, and rural definitions. Minimum travel paths are calculated using time and generalized cost on the highway system. The developed Travel Demand Model is used to forecast the Horizon Year loadings for each mode on all the links. Planning variables are forecasted for Horizon years based on demographics. The planning variables of horizon year form the input to the travel demand model along with the future highways and proposed transport facilities.

Trip ends are estimated and are fed into the calibrated gravity model along with base year highway skims. The distributed PA matrix so obtained is fed into the Mode split model and mode wise PA matrices are estimated. This forms the internal portion of the PA matrix. The external passenger PA portion as well as Commercial vehicle trips are estimated by Furness method (by taking 3% and 2% growth rate respectively) and added to the horizon year internal matrices. The combined PA matrix is converted into OD matrix and is loaded on to the PT and highway networks. It skims obtained from this assignment process are updated in the gravity model and redistribution of trips is done. Mode wise OD matrices are estimated by the updated skims. The final matrices thus produced are loaded on to the network, and the cycle is continued until the skims are stable. A brief discussion on study area characteristics is also presented in this study along with the network development. Then a lot of data needed for the study are collected from the past studies. The data set to include traffic data, planning variable data, transport system data, highway network and link attributes. With the enormous data available, Travel Demand Model is developed for the present study using CUBE software. Travel demand model is developed in CUBE platform, which is capable of producing outputs for sustainable transportation planning of Shiraz Metropolitan Area. Four-stage models basically trip generation, Trip Distribution, Mode Choice Modal and Trip Assignment has been explained thoroughly in this report along with the calibration required at each step.

3. Experimental data and results

The modelling structure will be based on the traditional four stages Travel Demand Forecast Model (TDFM) for the requirements of the study area. Shiraz city initially had eight municipality zones, which can be seen in Fig.2.a, but later 15 Traffic Analysis Zones (TAZs) and eight external zones have been applied, although Traffic Analysis Districts (TADs) which contained 157 internal zones (Fig.2.b).

Zonal layers and building network layer have been developed for this model; overlapping network layer can be seen in Fig.3.a. The road networks list which contains 1100 km length and 1800 nodes and identified nine different types of road links during the study. All these link's types were classified by capacity indices. (Fig.3.b)

- Maximum trip rate can be observed by one or two member household size.
- With increase in household size, trip rate decreased.
- Trip rate sharply depend to job category and economic situation. Salesmen with 3.36 have maximum and unemployed people are minimum with 0.09 trip rate per day.
- Car ownerships have more effect on trip rate. People without car have 1.51 trip rates but with one car ownership trip rate increase by 28.5% to 1.94 trip rate, also by two car ownership it increase by 47% to 2.22 trip rate daily. These important rates define as Mobility effect by car ownership parameter.

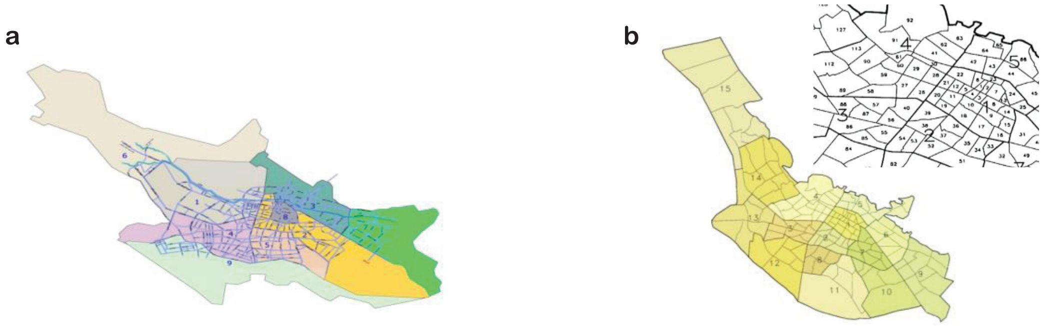

Fig. 2. (a) Municipality Zone; (b) TAZs & TADs zone arrangement.

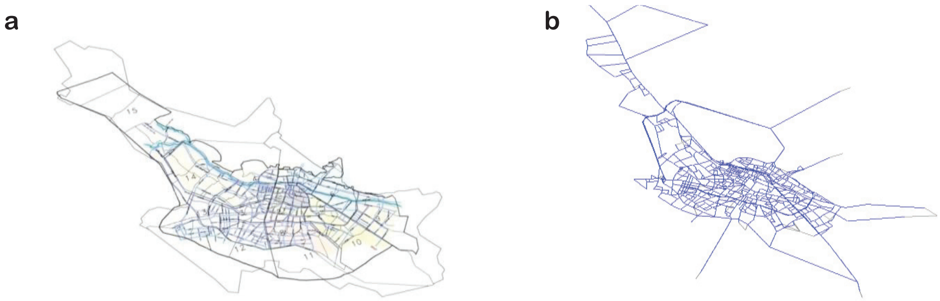

Fig. 3. (a) TAZs & TADs &Municipality overlap; (b) Network Building.

Table 1. Trip Rate in Iranian City.

City	Year	Tr. Rate
Shiraz	1999	1.68
Esfahan	1987	1.41
Shiraz	1988	1.37
Mashhad	1994	1.44
Tehran	1994	1.49

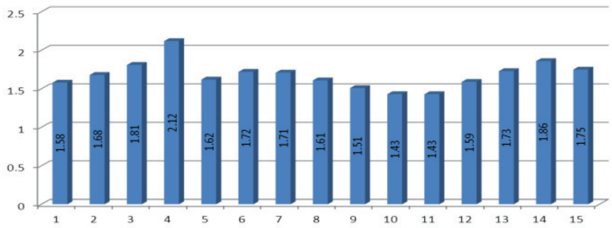

Fig. 4. Trip Rate by Different zone.

As it can be seen in Fig.4 the highest trip rate was in the zone. No.4 and second and third ranks were 14 and three zones. It can also be observed that economic situation has an inverse relation with household size. Furthermore, the least household size for zone No. 4 and 14, so high economic situation are for zone no. 4 and 14. Almost 44.9% of trips created by working people and remaining have assigned to unemployed population. Unemployment includes student with 26.7% trip and householder with 14.6% trip generation. Trip rate related to various cities of Iran in 1990s was tabulated in table1.

Y8 and Y10 were selected according to statistical studies; furthermore, coefficient of determination r^2, Standard Error, and t stat, indicate that these independent variables fit with population and vehicle plurality, household numbers and employment population well in the estimation model.

Y8 (Trip Production) =0.928X1(Population) +7.6437X4(All vehicle)-644.71

Y10 (Trip Attraction) =2643.47-0.403X1(Total of H.H) +0.490X2(All vehicle) +2.292X4 (Employment)

As per the methodology adopted in last part, base year networks have been developed to model the travel demand; previously, it was not generated network shape file for Shiraz's city. For network generation ArcGIS 9.2 and CUBE-Trip software packages were used. Shape file can be developed in ArcGIS, CUBE and Trans CAD software, but we developed shape file in ArcGIS. The following process was used to create the shape file:

- Set city Map image (*.jpg/*.tif)as guidance layer for help users to draw and recognize network status.
- Use actual geo data base file (*.dbf extension files) of links and node.
- Export attribute file (*.xls file) to shape file and define all necessary attributes.
- Define fuel stations by geo reference as a separate layer.
- Define node geo reference as a separate layer.
- Define two zonal layers for TADs &TAZs.
- Define capacity by CUBE-VOYAGER for each link
- Links and node numbering by C programming

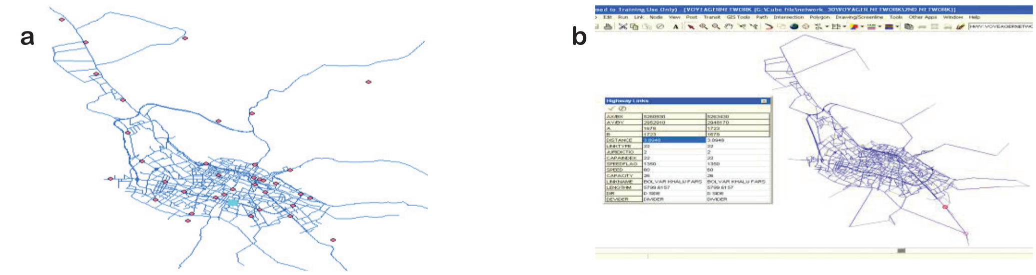

Fig. 5. (a) Fuel station layer; (b) Network with attribute.

Red points in Fig.5.a is shown petrol pump stations’ layer, which is loaded by attributes and coordination value and in front of that in Fig.5.b Network with attribute in the cube model is captured.

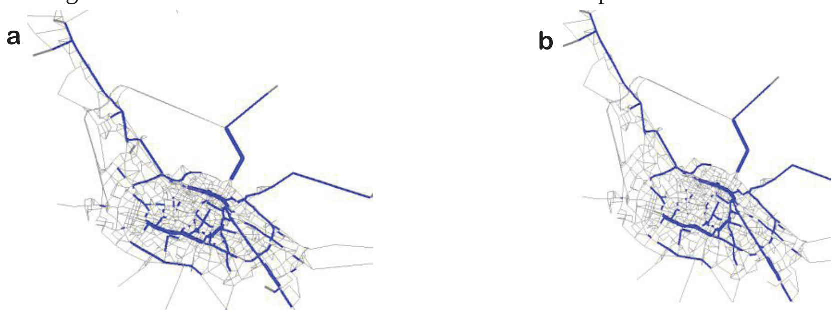

Fig. 6. (a) Final Car loading for TAZs (15 internal); (b) Car loading for TADs (167 zones).

Annual fuel consumption in 1999 in stations can be seen in Fig 7.a, furthermore, fig7.b demonstrated monthly consumption in the same year. Bar charts in Fig c, d illustrate details of P-A matrix and O-D matrix in eight districts, the similar trend can be seen in these figures and annual fuel consumption in 1999 in Fig7.a

Increasing number of vehicles because of excessive production and low price of petrol and cars in 2000s can be easily understood from the fuel consumption graphs. The dramatic rise (20 million liters per month) can be identified on fuel consumption from 2002 to 1999. This considerable growth can be also interpreted as inefficient use of public transport.

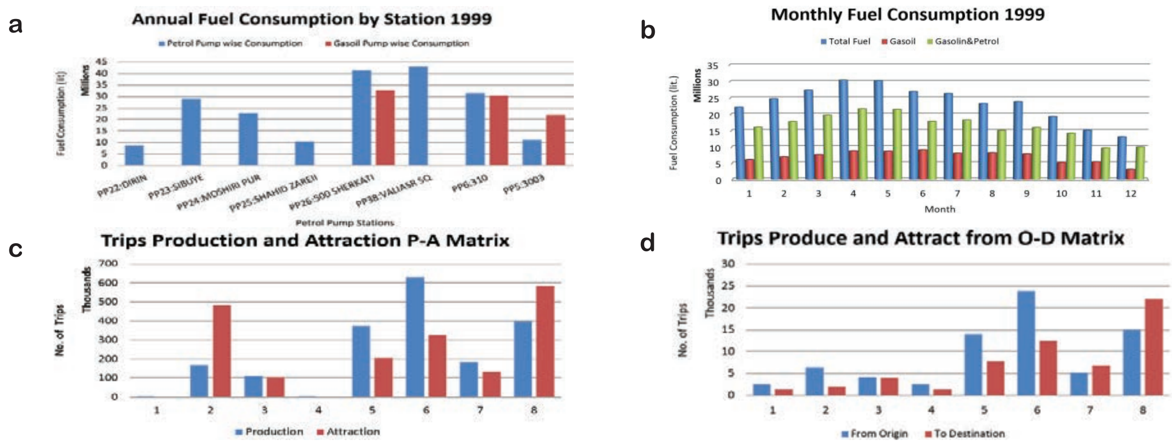

Fig. 7. (a) Fuel consumption in stations in 1999; (b) Annual Fuel consumption; (c)PA matrix trip base; (d)OD Matrix trip base.

4. Conclusions

As we can be seen, the independent variable for base year data (1999) was used to create trip generation and trip attraction regression analysis. Base year data characteristics and use of this equation helped in network creation. Eventually, the correlation and regression relationship was compared to other independent variables.

In trip production, the regression manner was shown to obtain residential, license, and regional vehicle population as the best variable for forecasting. On the other hand, for trip attraction, best regression manner was shown to obtain the total of household, regional vehicle population, and employment data as the better variable than license population. However, it's not significant and sufficient relation and tries to add student enrolment in the future for better and strong correlation. All above parameters were correlated strongly for TAZs but find weak relation in TADs. We use this method for testing and choosing the sense of independent variable with the dependent variable and create authoritative trip generation. The transports networks developed for base and horizon years are presented.

TDMF are developed for both TAZs (22 zones) and TADs (167 zones) plans, which should realize and be calibrated by sensitivity analysis in planning. Final vehicles loading for both plans as shown in Fig.6.a and Fig.6.b. Shiraz urban railway corridor plans are also based on both plans in such a manner that urban railway corridor and maximum traffic flow are overlapping. The planner should check and do research on the future effect of this overlap. Existing planning TDMF results helped planners to evaluate the urban railway corridor. As shown in the figure 7, fuel consumption of respective zone and petrol pump is a statistical function of O-D matrix, P-A matrix, but P-A matrix is related than O-D matrix. It requires a more detailed study of TDMF and consumption pattern to develop a model. In current TDMF made in 2010, important parameters for horizon year of 2012 had been calculated, with updating independent variables related to tripping production and attraction, which lead to trip quantity. The total number of trips has been estimated approximately 2 million trips and also 2 million liters petrol consumption had been observed per day in Shiraz's city. Considering the result of review of other studies, including 323 types of vehicle study regarding consumption and emission test in Iran, 2001, average of fuel consumption was estimated 16.3(lit/100km) for city trips. Consequently, vehicle distance travelled (VDT) can be calculated about 12.3 million kilometers per day, with average trip length of 6 km (as observed in base year TDMF) the total number of trips will be extracted 2 million trips. Based on careful analysis it can be clearly concluded that the strong and tangible correlation can be observed between fuel consumption and travel supply and demand chain. Studying of this topic can lead us to find the possible way to reduce any fuel consumption abuse related travel demand modelling.

Statistical results of this research prove that more reliable outputs can be obtained by use of parameters such as fuel consumption data, accessible and updatable statistical data, smart statistical data in intelligent transportation system, like as detailed information in fuel smart system and mobile BTSs, as independent variables; and establishment of independent variable's coefficients from correlation analysis and development of creative models.

In this study, the new and creative method for calculation of trip generation and distribution was proposed, by adjustment and comparison of different layer's attributes and conducting data mining procedure for available data and implementing of multiple regression models and use of backward analysis by cordon and screen line data with suitable CUBE software.

5. Acknowledgments

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