Multi-perspective Decision Support System for Hierarchical Bus Transportation Network Design: Tehran Case Study

Mehdi Ghatee[1], Seyed Mehdi Hashemi[2]

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Abstract:

In this paper, a multi-perspective decision support system (MP-DSS) to design hierarchical public transportation network is developed. Since this problem depends on different perspectives, MP-DSS consists of two sub-systems with macro and micro sub-systems based on travel information, land use and expert knowledge. In the micro sub-system, two sub-modules are developed considering origin-destination demand matrix and attractive places to travel. In the first sub-system, based on traffic assignment models, the bus corridors can be extended and by the second approach, connectivity between attractive places can be provided by new bus lanes. Multi-commodity flow problem and spanning tree problem are used in these two sub-modules to assign the public services to the corresponding networks. The corridors obtained from these sub-modules are evaluated by experts board module. These corridors are used to extend bus rapid transit (BRT), exclusive bus lanes between multiple districts and shuttle buses for trips inside of district. A prototype of MP-DSS is developed to illustrate the results on Tehran network. The most important contribution of this paper is to generalize the different mathematical models with land use and expert knowledge which substantially improves the results of network designing problem.

Keywords: Network optimization, DSS, traffic assignment, simulation, expert system.

Corresponding author E-mail: ghatee@aut.ac.ir

1-Assistant Professor, Department of Computer Science, Amirkabir University of Technology, Terhan, Iran

2- Professor,Intelligent Transportation Systems Research Institute, Amirkabir University of Technology, Terhan, Iran

1. Problem Description

Mobility and traffic congestion are two important concepts in every cities. Mobility can be provided by trunk public transportation system with great capacities and feeder services to access to public transportation; however the traffic congestion cannot be decreased only by mobility. In each city it is necessary to restrict private vehicles to harmonize flow through links (Penolosa (2012)). Based on this policy, in several cities in Asia, Europe and South America, the sustainable transportation networks are proposed. Sustainable transport refers to the broad subject of transport that is or approaches being sustainable. It includes vehicles, energy, infrastructure, roads, railways, airways, waterways, canals, pipelines, and terminals. Transport operations and logistics as well as transit-oriented development are involved. Transportation sustainability is largely being measured by transportation system effectiveness and efficiency as well as the environmental impacts of the system (Jeon and Amekudzi (2005)). As a result of such policy, the focus is changed to the environment and people health instead of infrastructure development and private cars. Thus it is necessary to extend subways, trolley buses and bus rapid transit (BRT). To encourage residents to apply these mass transit systems, sometimes traffic restriction is defined by municipality [Lou, 2011]. For example, Tehran consists of two kinds of restriction cordons to access central business districts (CBD), however the public transportation in these restricted cordons are week and so their effect on congestion is not acceptable. To improve this system, intelligent management systems including online routing, scheduling, monitoring and controlling should be extended in side of public transportation extension. Integration is also can be addressed by managing different modes under a unique department. For these aims, a decision support system (DSS) can be utilized, however the papers on DSS for network integration is very limited, see e.g., Ulengin et al. (2007) or Santos et al. (2008).

Public transportation network design is a complicated problem in CBD due to the social and political consequences. CBD residents usually have special customary which cannot be changed rapidly. The residents expect a right to access their homes with private car and it is very hard to limit such accessibility. So it is necessary to use a multi-criteria multi-constraint model to take all of the important concepts of this problem into account, see e.g., Cantarella and Vitetta (2006). Also cultural reformation and education should be programmed to exchange the resident enjoyment for travel with private vehicles. In extending DSS to design sustainable transportation network, the following critical
decisions should be concerned:

* Location of the depots and the main terminals,
* Location of transfer centers and their coverage,
* Capacity of transportation facilities,
* Installation of trunk lanes connecting important facilities,
* Installation shuttle buses to feed trunk lanes,
* Applying intelligent transportation systems to schedule, to guide and to simplify transferring.

To decide about these points, a lot of data gathering and data mining techniques can be considered in a multi-perspective decision support system (MP-DSS). On the other hand, the changes in the residents' behavior may be documented in an online MP-DSS to improve the system responses. In this paper the results of MP-DSS are given to improve bus system including bus rapid transit (BRT), exclusive bus lanes between districts and shuttle buses. For each of these networks different restrictions are taken into account and the dependency between them is implemented in a hierarchical plan in which BRT lanes are defined based on subways; Exclusive bus lanes between different districts are dedicated based on BRT lanes. Shuttle buses are defined to feed the other transit systems. Such hierarchical idea has been used for example by Lin and Yu (2012) for network design.

On the other hand, there are a great number of policies which can be followed for transit network design. For example highways or arterial streets for public transportation can be used in different models. Thus MP-DSS includes an important potential to implement different models and policies. MP-DSS can be also used to design the network with offline and online data. For example by saving the queries received by a route guidance system, it is possible to estimate the number of travelers between origins and destinations and to decide about the future extension in transit networks. MP-DSS framework includes the following concepts of intelli-

gence:
1- Learning experts' experience to meet restrictions on transportation modes;
2- Flexible in case of demand variations;
3- Reasoning-based modeling of transit network;
4- Dealing with perplexed situations because of travelers' behavior and social consequences;
In what follows, some preliminaries of MP-DSS are presented. In Section 3 and Section 4, the details of data bank and model bank of MP-DSS are given. Section 5 includes the results of MP-DSS on Tehran. Final section ends the paper with a brief conclusion.

2. MP-DSS for Transportation Network Design

The transportation in developing world is poor in view of accessibility, time, safety and energy. To improve these drawbacks, sustainable transportation designers focus on human instead of vehicles and environment instead of development. In sustainable transportation, the highest priority corresponds to the public transportation which causes to design a public transportation with the most coverage and accessibility. In sides of public transportation network, appropriate pedestrians together bike routes should be extended. The usage of sustainability is also dependent on the level of intelligent transportation systems which simplifies the usage of public transportation. These systems can be also used to find the activities and the sources to estimate flow over time, see Fig. (1).

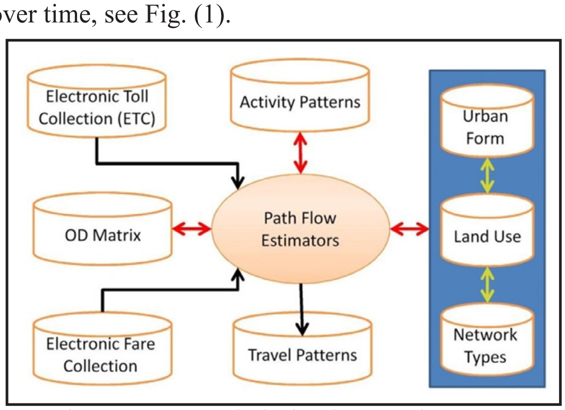

Figure 1. Network design by travel patterns

For example electronic toll collection system can be used to find the number of vehicles coming in a restricted zone. Also from fare collection system, the number of passengers can be estimated. In MP-DSS the information is gathered per each time interval. In addition land use are provided by MP-DSS to find the influence on travel demands. Fig. (1) shows data bank of MP-DSS. The blue box in Fig. (1) shows only geographical information. Others can be indirectly saved in geographical information system (GIS). For example the activity patterns can be augmented into GIS and its update can be used in network analysis.

MP-DSS is an interactive computer-based system consisting of GIS and different perspectives which can be used to help decision makers to use communications technologies, data, documents, knowledge and/or models to identify and solve problems, complete decision process tasks, and make decisions, see e.g., Fierbinteanu (1999), Cheung et al. (2005). In MP-DSS to design sustainable transportation network, we combines the viewpoints of stakeholders to find the attributes and decision factors. Sometimes checklists are used to extract important concepts for stakeholders. Then reasoning-based methods are used to create models and heuristics, simulations and mathematical methods are used to design the necessary transit network, see e.g., Lin and Yu (2012).

A great number of algorithms for network design focus on a very special data, however network design is a multi-disciplinary problem and should be solved considering different points of view. In MP-DSS the integrated public transportation network is designed applying different policies which can be given with criteria or restrictions. The advantages of MP-DSS are its global view to different approaches, methods and experiences through network design. Also the variation of behavior and environment can be reflected in MP-DSS to improve the results. MP-DSS combines the results of different design approaches made by transportation engineers and management departments. For example, the bus fare can be decreased to increase the number of travelers for a new installed bus lane.

In a lot of network design processes hierarchy extension is followed for example by Guha et al. (2000). In this approach, the problem is divided into multiple levels and the network design for each level is done only by considering higher level networks and then it is possible to define a long-term program to extend the network of each level in several months. In MP-DSS

there are three levels for extending public transportation network:
1. Bus rapid transit (BRT) system,
2. Exclusive bus lanes through arterial streets to connect several districts,
3. Shuttle buses for trips inside of district which are the feeders of mass transit systems of the previous levels.
In the first level, based on comprehensive study in city, the main skeleton for subway system and BRT is studied. In the second level some exclusive bus lanes are installed to cover far trips between origins and destinations of different districts. In this part spanning tree or Steiner tree can be used to find appropriate routes. In CBD these lanes are defined similar to grid which simplifies accessing to important nodes. In the third level the different vehicle-size para-transit systems are installed namely shuttle buses in which the travel inside of district is supported. The shuttle buses can be defined by expert panels considering gaps in transit network and analyzing accessibility measures in network. MP-DSS framework depicted in Fig. (2), is proposed for this aim.

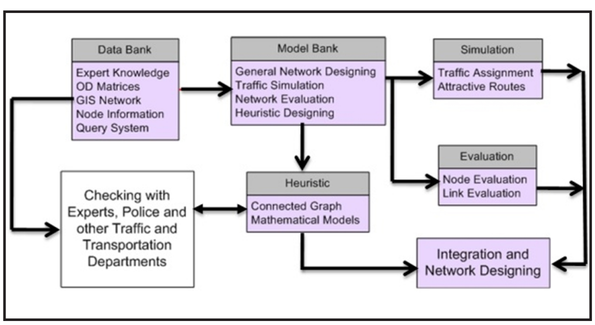

Figure 2. MP-DSS framework to design the integrated public transportation network with respect to the different ideas.

As one can note that MP-DSS includes 2 subsystems:
1. Data bank;
2. Model bank;
The model bank includes 4 subsystems in order to design network by classical, simulation, evaluation and heuristic perspectives. In what follows we discuss on data bank and model bank in the proposed MP-DSS.

3. Data Bank in MP-DSS

Geographical information is the base for network design process. MP-DSS includes several sources of information. The most important data used in MP-DSS is expert knowledge about urban restrictions and travelers' behavior, see Talvitie (2006). Some important ideas for network extension can be also extracted from this knowledge. This part of MP-DSS can be exhibited with fuzzy quantities and relations using inference engines. Also between different criteria, some pair-wise comparison is needed.
The second part of data bank of MP-DSS is origin-destination travel demand (OD matrix). OD matrices can be annually estimated by data gathering or some statistical estimation techniques; however this is expensive and includes incomplete information. Instead of this heavy process, by applying sensors in important nodes, it is possible to estimate such matrices automatically. Finding the best locations for sensors is also noticeable, see e.g., Ehlert et al. (2006). Data fusion techniques are also very important in this category, see e.g., El-Faouzi et al. (2011).
Geographical information system of urban network is also the main base for transportation network extension. GIS has been previously utilized for a decision support system for location problem by Kolli et al. (1993), for urban transportation policies planning by Arampatzis et al. (2004). To select the links for public transportation, it is possible to define a weighted formula to rank links. The high ranked links are selected for bus exclusive lanes. These weights are based on decision makers' policies.
The other information which can be considered by MP-DSS is important origins and destinations for travelers. For example, malls, hospitals, universities, official departments, etc, can be considered as attractive places to travel. The connection between these places is essential to design public transit network to travel between these different places.
Intelligent transportation systems (ITS) devices are also another source of information; for example, by electronic toll collection (ETC) and electronic fare collection (EFC) systems, it is possible to count the number of users coming to and exiting from a zone. Also it is possible to estimate the OD matrix with an appropriate accuracy. These kinds of information are very important when a hierarchical design approach is following. Based on the hierarchical approach, the data bank of MP-DSS framework for each level is different from

other levels. The main sources of data bank for level t are presented in Fig. (3).

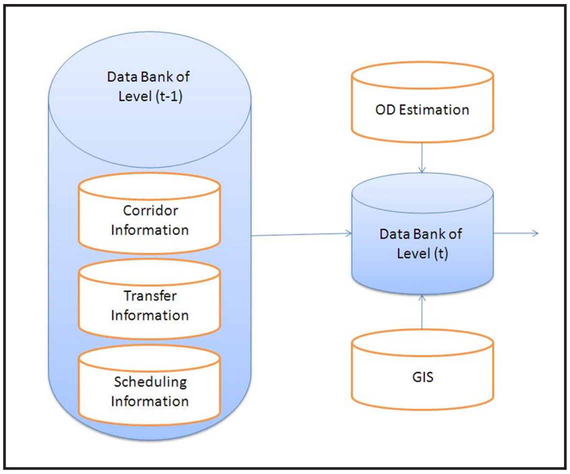

Figure 3. Data model of MP-DSS in the successive levels.

The information on corridors and transfer points are used to plan the transportation lanes. In this source, some quantified and qualified information may be collected. As an instance, the experts' policies about the corridors can be considered in this information source. Transfer information is gathered by different levels. The scheduling information is also used to adjust frequency of service in each level with respect to the different levels. Based on the results of MP-DSS, it is possible to decide about the necessary mode in each level to provide reasonable service. For such design, the following intelligent data gathering systems can be implemented:

* Electronic toll collection;
* Fare collection system;
* OD matrix estimation using mobile phone;
* Query-saving module of route guidance system.

The fare collection systems can be used to obtain the number of transfers. By mobile phone information, it is possible to estimate the origin-destination information with respect to the source and destination of the mobile phone's owner. Also by query saving modules, it is possible to save and combine the number of residents who wish to travel on a path between a couple of origin and destination and the mode chosen by travelers. These data are integrated to design a network for each level with respect to the previous levels.

4. Model Bank in MP-DSS

In developing countries usually there are some strategic plans to extend public transportation networks. For example in Tehran, municipality tries to provide attractive and rapid public transportation facilities including dedicated runways in CBD in a way that in case of enforcing traffic restricted zone rules, public transportation network would be available within a distance not more than 350 meters walk from origins. It is necessary to define such strategies in MP-DSS to present satisfying solutions. These strategies are used to choose appropriate conceptual model in model bank.

In conceptual modeling of model bank, two different sub-models can be followed: Macro and micro models. The first model provides a global view about the number of horizontal and vertical transportation lanes and their headways, see Daganzo (2010) for details. The second one is used to describe the details of transportation lanes which should be developed. These models can be categorized into two different models:

1. OD-based models;
2. Attractive places to travel models;

OD models apply multi-commodity flow or traffic assignment problems in order to estimate the flow through links. The other models connect attractive places. The following two kinds of software can be pursued for such OD-based models:

* Traffic simulation software such as AIMSUN or EMME/2 to solve user equilibrium or stochastic user equilibrium problems;
* Optimization software such as AMPLE to solve a multi-commodity flow problem in order to obtain the number of travelers on the paths and links;

In the first approach the effect of the traveler perception on congestion can be exhibited, however the second one is a strategic plan for travel, see e.g., Ghatee and Hashemi (2008).

4.1 Macro Model in MP-DSS: Conceptual Models

In a macro model, the network shapes and operating characteristics of a transit system is evaluated according to the accessibility level. For this aim, it is possible to consider the city as a square with uniform demand. On this square, Daganzo's model (2010) generates master plans of transit systems including the structure and technology (bus, BRT, or subway).

Another approach in conceptual models is analyzing the OD matrix information. In MP-DSS it is possible to reveal the most important desired lanes of travel between origins and destinations and also between districts. These lanes can be followed in the geographical map to propose some mass-transit lanes by experts. It is important to note that in conceptual models it is not necessary to determine the details of bus plans such as headway, number of passengers and transfer points. These models present the shape of public transit network. In micro models the details of public transportation system can be studied.

4.2 Macro Model in MP-DSS: Group Decision Making Models

Sometimes in results of MP-DSS, there are some areas with poor access to public transit. For such areas it is possible to define shuttle buses to provide accessibility. Such system has been installed in Seoul successfully, see Kim et al. (2011). The main targets of shuttle buses are as follows:

* Provide more travel choice for the residents
* Create job opportunity based on small-sized and medium-sized bus companies
* Attract the short travel distance commuters and thus compete with taxi service
* Servicing as a feeder for the residents living in an area with poor access to public transport

The shuttle buses are provided in a side village, a remote village, apartment complex, an industrial park, schools, and religious institutions.

Each shuttle bus starts from a residential area and connects to a nearest subway station or a larger regular bus stop and then return to the origin point. Thus their paths are similar to a cycle or semi-cycle. In MP-DSS there is a module to gather the proposal made by effective members such as city government, district office, shuttle bus association, city bus association, city society, etc. Then by using a multi criteria decision making algorithm such as AHP or ANP, it is possible to rank proposals and to combine the shuttle buses route in each city district.

4.3 Micro Model in MP-DSS: Attractive Places to Travel

Transportation oriented development (TOD) viewpoint can be noticed as a policy for public transit network design. Based on this viewpoint, the connection between attractive places to travel should be installed and the residents and organizations match themselves to this skeleton structure. For this aim, in MP-DSS by saving the experts' knowledge and information centers about some places with great number of visitors in geographical data base, it is possible to define a connected network. Some of these places such as great hospitals, markets, universities, ministry departments and public facilities are ranked in GIS and others can be found by filling the information forms in taxi driver organizations, police and district officers who are familiar with the residents travel behavior.

To present a mathematical model based on this idea, consider the set $P = \{ p_1, p_2, ..., p_n \}$ of n important attractive places. Consider a weighted graph whose nodes set is P. The link between p_i and p_j is related to a path in city which can be used to install as a public transportation lane. The weight of link (p_i,p_j) is the construction cost of an exclusive bus lane. On this graph, we need to find minimum spanning tree or Steiner tree, see Ahuja et al. (1993). Also note that in MP-DSS, the weights of attractive places can be found by AHP technique (Saaty, 2004). In addition, when MP-DSS finds a minimum spanning tree, it searches whether or not all of the attractive places are connected in tree with a path including at most three links. Otherwise the direct paths between these places are augmented to tree. This new sub-graph includes possibly some cycles, however this result provides a more reliable transportation system.

4.4 Micro Model in MP-DSS: OD-based Models

In a great number of studies on network design problem, the OD matrix is used to estimate the flow through different links. It is possible to install the transportation mode t through link (i,j). The following multi-commodity flow model can be stated to define which of the public transportation modes should be installed in integrated public transportation network to satisfy travel demands:

$$\min \sum_{k=1}^{K} \sum_{t=1}^{T} \sum_{(i,j)\in A} f(c_{i,j}^{k,t}, x_{i,j}^{k,t}, u_{i,j}^{t}) + \sum_{t=1}^{T} \sum_{(i,j)\in A} g(\mu_{i,j}^{t}, z_{i,j}^{t}, u_{i,j}^{t})$$

s.t.

$$\sum_{t=1}^{T}\sum_{j:(i,j)\in A} x_{i,j}^{k,t} - \sum_{t=1}^{T}\sum_{j:(j,i)\in A} x_{j,i}^{k} = b_i^k, \quad \forall i,k$$

$$0 \le \sum_{k=1}^{K} x_{i,j}^{k,t} \le u_{i,j}^{t} z_{i,j}^{t}, \quad \forall (i,j)\in A, \forall t.$$

where $x_{i,j}^{k,t}$ is the number of travelers who select the link (i,j) with transportation mode t to travel between the k^{th} origin and destination pair. $c_{i,j}^{k,t}$ is the corresponding free-flow cost. Also $u_{i,j}^{t}$ is the capacity of mode t through link (i,j). Then function $f(c_{i,j}^{k,t}, x_{i,j}^{k,t}, u_{i,j}^{t})$ shows the transportation weighted costs. As an instance, when for all of the origins and destinations, the fixed free flow cost $c_{i,j}^{k,t} = c_{i,j}^{t}$ is considered, can be stated as follows:

$$f(c_{i,j}^{k,t}, x_{i,j}^{k,t}, u_{i,j}^{t}) = c_{i,j}^{t}\left(1+\alpha\left(\frac{\sum_{k=1}^{K} x_{i,j}^{k,t}}{u_{i,j}^{t}}\right)^{\beta}\right)$$

where α and β are two fixed parameters.

Variables $z_{i,j}^{t} \in \{0,1\}$ in the network design objective function are associated with the construction of transportation mode t through link (i,j) in which $z_{i,j}^{t} = 1$ if transportation mode t on link (i,j) belongs to the final solution of network design problem, otherwise $z_{i,j}^{t} = 0$.

$\mu_{i,j}^{t}$ is a fixed installation cost of transportation mode t. The associated cost of this installation in link (i,j) is given by $g\left(\mu_{i,j}^{t}, z_{i,j}^{t}, u_{i,j}^{t}\right)$. The objective function of the network design problem is the sum of variable and fixed costs. The fixed installation costs cannot be presented in direct manner because of different parameters based on social consequences, political decisions, etc. An expert system for an urban network can be used to evaluate the cost function g with respect to the previous experiences. For example, this function can be imitated with a multi-layer perceptron (MLP), see e.g., Ghatee and Hashemi (2009).

b_i^k in network design problem is also a positive number if node i is the origin of k^{th} pair and is negative if i is the corresponding destination. Otherwise it is zero. The first group of constraints in network design problem satisfies the transportation demand and the second group guarantees to use a link after mode installation and the flow is restricted with the mode capacity $u_{i,j}^{t}$. Usually b_i^k is given by transit distribution techniques such as Logit model on OD matrix. They can be also estimated by data warehouse of MP-DSS, see e.g., Wang et al. (2010), Mussone et al. (2010).

In MP-DSS because the network design problem includes a great number of integer variables and MP-DSS cannot solve the model in a reasonable time, a hierarchical approach is used in which the processes of transportation mode selection and link selection are combined. For this aim, only link flow variables are considered and the transportation modes are defined with respect to the the number of users through links in next step, i.e., in the optimal solution when a link includes a great number of travelers, a mass-transit is proposed for the link, otherwise shuttle buses are proposed to service such links. This simplified model is as follows:

$$\min \sum_{k=1}^{K}\sum_{(i,j)\in A} f(c_{i,j}^{k}, \mu_{i,j}, x_{i,j}^{k}, u_{i,j})$$

s.t.

$$\sum_{j:(i,j)\in A} x_{i,j}^{k} - \sum_{j:(j,i)\in A} x_{j,i}^{k} = b_i^k, \quad \forall i,k$$

$$0 \le \sum_{k=1}^{K} x_{i,j}^{k} \le u_{i,j}, \quad \forall (i,j)\in A.$$

in which $u_{i,j}$ is an approximate upper bound on the capacity of link (i,j). In MP-DSS the objective function is stated as follows:

$$f(c_{i,j}^{k}, \mu_{i,j}, x_{i,j}^{k}, u_{i,j}) = (c_{i,j}^{k} + \gamma\,\mu_{i,j})\left(1+\alpha\left(\frac{x_{i,j}^{k}}{u_{i,j}}\right)^{\beta}\right)$$

in which $\mu_{i,j}$ depends on the number of lanes in each street which can be used for exclusive bus lane, $c_{i,j}^{k}$ is the link capacity and $u_{i,j}$ is the weighted transportation costs. α, β and γ are three important parameters which can be given by decision maker. This model is a minimum cost multi-commodity flow problem. In MP-DSS, r-shortest paths are obtained between each pair of origin-destination and then the flow through these paths are calculated applying decent direction algorithm, see e.g., Sheffi (1985).

After finding the flow through each link, the link flows $x_{i,j} = \sum_{k=1}^{K} x_{i,j}^{k}$ are sent to a threshold function which ranks the links into the following classes:

* [$x_{i,j} \geq \theta_1$] For installing bus rapid transit (BRT) in link (i,j);
* [$\theta_2 \leq x_{i,j} < \theta_1$] For installing exclusive bus lane in link (i,j);
* [$x_{i,j} < \theta_2$] For installing shuttle buses in link (i,j).

The threshold parameters θ_1 and θ_2 are given by decision maker.

4.5 The Structure of MP-DSS

In conclusion of this section, it is possible to present the framework of MP-DSS. As one can note in Fig. (4), MP-DSS consists of two parts; Data bank and Model bank. The model bank considers macro and micro models to define public transit and para-transit networks. To integrate the results of all the models in order to define mass transit network and shuttle buses, multi-criteria decision making process are called. In the proposed MP-DSS it is possible to add some models such as reasoning-based models in order to design public transportation regarding to real restrictions. In next section the results of MP-DSS is presented on a pilot.

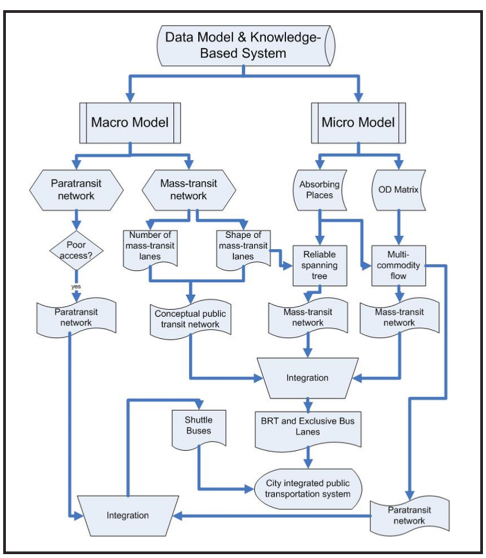

Figure 4. MP-DSS framework to design integrated public transportation network.

5. The Results of MP-DSS on Tehran City

Tehran with more than 8 million residents, 640 square kilometers area, more than 3.5 million vehicles and more than 2.5 million motorcycles needs an integrated, available, safe, easy, comfortable, clean and reliable integrated public transportation network. Such system should be designed with respect to an irregular network of public ways with 2700 kilometers in length in which 14% are highways and 27% are arterial roads to transport 15.6 million daily origin-destination trips. At the first program of sustainability in Tehran the restricted traffic zone was founded which is the base for traffic restriction and sustainable transportation. The area is open only to ambulances, fire engine, police vehicles, diplomatic vehicles, public vehicles including buses, minibuses and taxis during specific hours of the day (6:30am-5pm). In July 2010, Tehran instituted a congestion charging system, using camera-based license plate recognition technology to monitor and enforce. Drivers are required to buy a pass (available annually, weekly or daily) in order to enter the charging zone.

Tehran has developed a comprehensive public transport policy. By 2009, Tehran had 159 kilometers of urban subway. By 2010, an additional 77 kilometers were added, increasing annual passenger trips by 17 million for a total of 459 million trips per year made on the subway system.

In addition to its urban subway system, Tehran began implementing Bus Rapid Transit (BRT) in 2007. The city expanded the BRT network by 17.5 kilometers in 2009 and 21.5 km in 2010, for a total length of 91 kilometers in 2011. In 2011 the system carried 1.4 million passengers for a day. In 2010, an integrated electronic fare system has been also debuted for the subway and public bus services, which is being expanded now to shuttle buses.

On the two most recent BRT lanes, the number of people using public transport is increased by 31% and 35% respectively and passengers received a 24% and a 42% time savings, respectively, on their trips in comparison with the time they were using before.

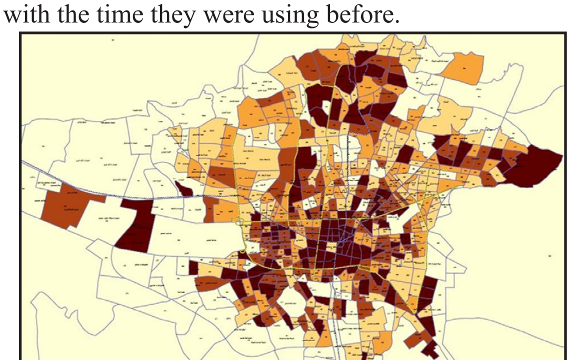

Figure 5. Land use in Tehran with respect to a weighted combination of different factors (The darker color shows the higher land use).

In the first results of MP-DSS for Tehran, as one can see in Fig. (5), the land use of Tehran zones are depicted with respect to the activities saved in the geographical information of MP-DSS. This figure shows that there are some colony of important regions in the center and the north of Tehran, which should be serviced with important mass transit lanes.

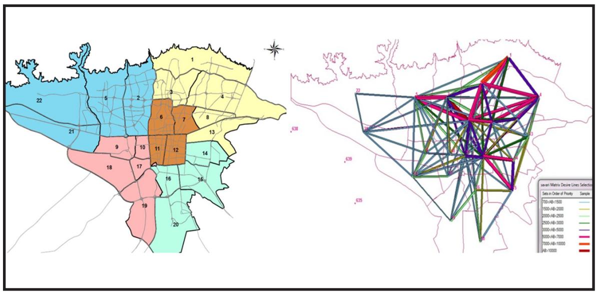

Figure 6. (The left): Conceptual modeling on Tehran in which the districts 6, 7, 11 and 12 are selected to extend grid network with 8 horizontal and 7 vertical trunk lanes. (The right): The classification of travels in Tehran with respect to the number of travelers between two different districts.

By applying conceptual model of MP-DSS in Tehran, 4 districts of 22 districts of Tehran can be selected to reinforce public transportation. These districts are shown with dark color in Fig. (6).

In this figure, the desired lanes are also presented which shows residents tendency to travel to these districts. Applying Daganzo's model (2010), MP-DSS reveals that 8 horizontal mass transit lanes and 7 vertical mass transit lanes can be defined to service in these districts corresponding to Tehran CBD.

Also according to the micro model of MP-DSS, it is possible to define a reliable connected tree.

In results of MP-DSS for Tehran, in order to enhance the reliability, the important places with distance over than L=3000 meters are selected and a direct public transportation between these nodes are defined, see Fig. (7).

In addition, using multi-commodity module of MP-DSS in Tehran CBD, as mentioned in Fig. (8), the links with less than 8000 passengers per hour are colored with yellow, the links with passengers between 8000 and 20000 per hour are colored with violet and the links with flows more than 20000 passengers per hour are colored with red.

Figure 7. The results of MP-DSS for connecting attractive places to travel.

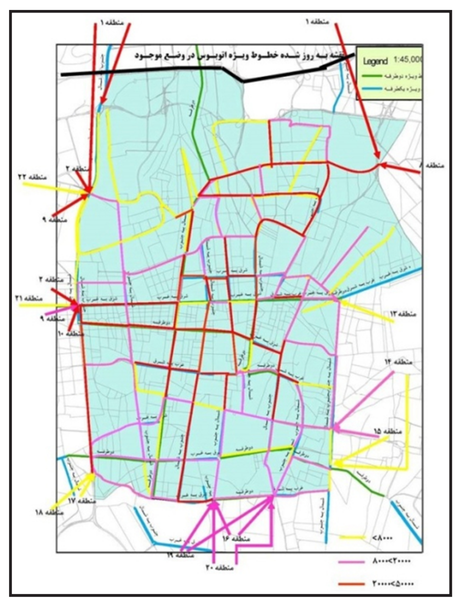

Figure 8. The results of multi-commodity flow problem in Tehran CBD.

Using the integration module of MP-DSS, in Fig. (9), the exclusive bus lanes of Tehran is presented. Details of these mass transit lanes are given in Table (1).

To feed the mass-transit lanes depicted in Fig. (9) the paratransit module of MP-DSS is called. As depicted in Fig. (10) the shuttle buses routes are defined in order to feed all of the mass transit lanes of Tehran.

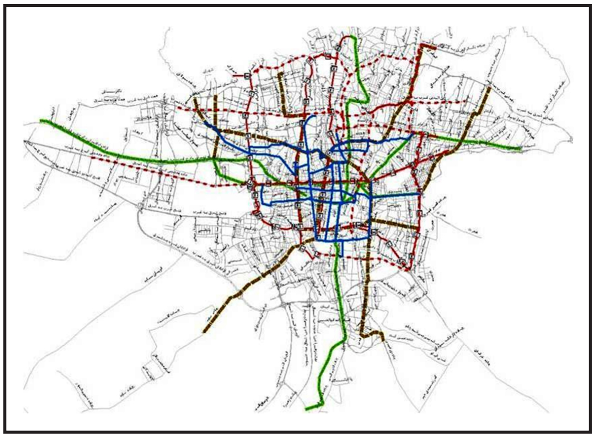

Figure 9. The results of Tehran exclusive lane in Tehran.

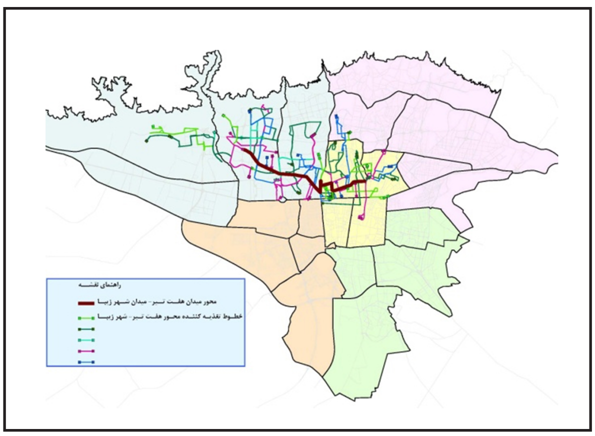

Figure 10. Shuttle buses as the feeders of a mass transit lane in Tehran depicted with width lane.

6. Conclusion and Future Directions

Integrated public transportation network has been followed by a lot of developed cities, however there are very different topics which should be solved in such network design. In this paper, the structure of a decision support system (DSS), namely MP-DSS, is proposed to design integrated public transportation network . MP-DSS consists of data bank and model bank. It is possible to consider different policies in MP-DSS. In the case of low accuracy of OD matrix, the experts' knowledge can be substituted in the presented MP-DSS. The outcome of MP-DSS is a network including mass transit lanes and shuttle bus system.

We implemented a prototype of the proposed DSS and used for public transportation network in Tehran. We showed that the different data and experience can be used in a unique network design process in order to design an applicable network design instead of a theoretical one. Also because the feeder services are designed together with trunk services, it is very easy to integrate the public transportation services.

In future works multi-modal routing can be added to MP-DSS to propose optimal routing and scheduling.

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Table 1. The details of the proposed exclusive bus lanes for Tehran sustainable transportation network.

Index	Covered Population	Length (Km)	Daily passengers
Line 1	56110	8.9	142329
Line 2	75852	11.6	192406
Line 3	47061	10.3	119375
Line 4	344455	30.7	873745
Line 5	117989	24.4	299291
Line 6	107547	17.4	272804
Line 7	125100	21.8	317329
Line 8	171012	22.1	433789
Line 9	82837	10.3	210124
Line 10	95962	12.9	243417
Line 11	65422	10.9	165950
Line 12	79609	10.7	201936
Line 13	106784	15.6	270868
Line 14	77267	11	195996
Line 15	56976	9.8	144525
Line 16	99698	13.1	252894
Line 17	64346	12	163220

Tahmasbi, Mrs. Mahshid Falsfi, Mr. Hoseyn Mousavi, Mrs. Elnaz Irannejad, Mrs. Narges Abolghasemi, Mrs. Somayeh Soodmaand, Mrs. Elahe Hajhashemi and other members of ITSRI and ITDP for their valuable recommendation which are used to gather and to improve this paper.

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