A DECISION SUPPORT SYSTEM TO IMPROVE SERVICE QUALITY IN MULTIMODAL RAPID RAIL SYSTEMS: A BAYESIAN PERSPECTIVE

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Abstract: In this study, the accessibility of the rail transit stations in a multimodal network formed by a trunk line and its feeder lines are defined. Connectivity between lines and the accessibility of the nodes identify the overall spatial structure of the network. The factors influencing the access choices of rail transit stations and satisfaction of transit travelers in rapid rail transit systems are investigated in order to gain insights into the factors and their interrelationships. The quantitative indications of the relationships are produced and the complexity of evaluating the performance of transit services is exhibited. As the interrelationships are mainly stochastic, the problem on hand is treated as a Bayesian Belief Network (BBN). A BBN approach that presents a learning mechanism is employed and is used as an alternative decision making tool to analyze the rapid rail transit services and identify policies to improve the traveler's level of service.

Keywords:Multi-Criteria Decision Making, Real Life Applications, Transportation and Traffic

1. Introduction

Recent efforts on transportation planning and urban policy making often focus on increasing transit ridership through improved technological, operational and service efficiencies. The ultimate goal of increasing the share of transit would result in decreased environmental stress with lower gas emissions and higher energy efficiencies as well as increased quality of life in urban areas by less congestion and less pollution. Urban rail systems offer major advantages for promoting the transit travel as a trunk line with high speeds, high capacities and its own right-of-way. However, the ability and willingness of travelers to make transit travels are influenced by the characteristics of rail transit such as network coverage, price, travel time, reliability, service schedule, and the station accessibility (Lindsey *et al*., 2010).

Trunk-feeder system is introduced to reduce some of the inefficiencies generated by heavy flows of competing buses. Feeder lines carry passengers from suburbs to the trunk where the passengers interchange for lines distributing to the city. The operation is reversed in the afternoon for passengers leaving work and going back home. In this study, we focus on trunk and feeder systems and define the accessibility of the rail transit stations in a multimodal network formed with a trunk line and its feeder lines. Connectivity between the trunk-feeder lines and the performance of the services identify the level of service in the multimodal network.

The factors that influence the performance of transportation services are various. Among them, many are stochastic in nature. Thus, these factors may be uncertain, the information about them may be incomplete, and their interrelationships may be non-linear. Moreover, these factors are commonly highly-correlated. For example, the performance of transportation services is a function of the usage of the service. The performance function is typically an increasing non-linear function of the flow which is a random variable distributed across time and the transportation network. Besides, perception of the performance of the transportation systems (e.g. travel time) is also a random variable distributed across the population of passengers. So, there is a distinction between the actual performance and the perceived performance. The traditional methods often cope with these difficulties under various assumptions.

This study represents the factors and the influences in a network structure. A Bayesian Belief Network (BBN) approach that presents a learning mechanism is used as an alternative decision making tool in order to analyze the rail rapid transit services and identify policies to improve the traveler's level of service. This paper is organized as follows: Section 2 explains the methodology proposed in this research and the application of the proposed methodology in the case of Istanbul Metro. Section 3 discusses the results of the case study, concludes the paper, and provides suggestions for the future studies.

2. Proposed Methodology and the Case Study

This research employs a four stage methodology. In the first stage, the key variables affecting transportation system are identified by literature review (Bates, 2000; Bates *et al*., 2001; Ben-Akiva *et al*., 1993; Brownstone and Small, 2005; Burris and Pendyala, 2002; Bowman and Ben-Akiva, 2001; Hess *et al*., 2005; Lam and Morall, 1982; Lam and Small, 2001; Lindsey *et al*., 2010; Lyons and Urry, 2005; Murray, 2001; Noland and Small, 1995; O'Sullivan and Morall, 1996; Small *et al*., 2005). In the second stage the causal relationships of the variables are revealed through causal maps since these maps represent domain knowledge in the form of directed cause–effect relationships between variables in a more effective way than alternative models such as regression and structural equations (Nadkarni and Shenoy, 2001). In the third stage, the causal maps are transformed into a BBN which is an acyclic directed graph and this graph is used to represent the conditional dependencies as well as the uncertainties of these variables. Although the relations represented in a BBN do not have to be causal, this research makes use of causal maps to reduce the problems encountered in specifying both the key variables and their causal relationships (Nadkarni and Shenoy, 2004). BBNs are thus also referred as causal belief networks where the dependence relations are causal. In the fourth stage, a sensitivity analysis is performed using the BBN to determine impacts of the most critical variables affecting customer satisfaction in multimodal transportation. Hence it becomes possible to identify varying nodes for which a finding will provide the most information about the variable in question. The proposed model which is tested with the case of Istanbul Metro is expected to provide assistance to public transport authorities for improving the quality of services and the user satisfaction.

The data of the case study is obtained from a customer satisfaction survey conducted at a metro line (M2) which operates with 11 stations in a highly populated central business district in Istanbul. The data set involving 750 observations includes information regarding the access part of the transit travels but not the egress part. As a consequence, we characterize the multimodal transit travels with two variables, mode used for accessing the metro station and the departure metro station. In a typical working day, at least 60% of the journeys made by M2 are multimodal transit journeys including at least one transfer between the metro and a connecting line of another mode (Ugurlu, 2011). The performance of the integrated services including a metro trip and the number of travelers attracted by metro depends highly on the services of its connecting modes. Fifty five percent of the transit travels are connections from bus lines, 30% from the Bus Rapid Transit (BRT) line, 10% from minibuses and 5% from the funicular line. The connections of the transit travels are concentrated in three stations which have the highest traffic (about 100,000 passengers per day) of all stations. The connections in the stations, namely Sisli, Taksim and Levent, constitute approximately 63% of the connections of the metro transit travels.

The traveler satisfaction ratings provided in the dataset is used to extract main service quality dimensions. Factor analysis is conducted to identify the main dimensions from a high number of satisfaction questions. Due to multi-collinearity problem with the factor analysis of 23 satisfaction questions of the survey, the importance ratings of the passengers are used to point out the most important 10 satisfaction questions: consistency to the declared time plans, travel time, waiting time, access to the station, the safety and security level in the station, the safety and security level in the vehicles, the manner and attitudes of the security personnel, the cleanliness of the vehicles, the air condition system in the vehicles, the level of crowdedness in the vehicles. Sixty three percent of the variance is explained by the factor analysis: 4 main service quality dimensions, representing the passenger perceptions of the service performance, are identified: accessibility, comfort, safety and security, and time. "Accessibility" is identified as a service quality dimension related to the ease of access in the metro station and waiting time of the traveler. "Comfort" includes the passenger satisfaction level related to crowd in the vehicles, temperature in the vehicles and cleanliness. "Safety and security" dimension involves the security perception of passengers against crime in the stations and vehicles as well as safety perceptions related to accidents. "Time" as a service quality dimension represents the perception of passengers about the travel time and consistency of vehicles to the time plan. The four quality factors extracted from satisfaction questions are used to figure out the relation between the level of service delivered to the passengers and passenger expectations from the service (Parasuraman *et al*., 1985).

Since passenger expectations generally arise from the needs or characteristics of the individuals, passenger characteristics used commonly in the literature such as gender, level of income and car availability are also included in the analysis. Ticket type variable represents expectations and needs of different passenger groups. Gender is involved to observe the differences among male and female travelers. Level of income is used to reflect the priorities of different traveler groups with varying income levels. Car availability of the travelers is included to represent the effect of having car mode as a travel alternative. Spatial separation is used as a variable representing the travel characteristic of the passenger. Besides, total travel time and access travel time are involved as quantitative indicators of the performance.

Determination of the causal relationships among variable pairs is carried out via interviews with experts. Three experts, who are volunteers to cooperate, are chosen based on their knowledge and experience for this purpose: an urban planner who works for Istanbul Metropolitan Planning Center; a civil engineer who is working on public transportation planning; an academician whose major research areas are systems engineering, transportation planning and vehicle routing. The resulting pairwise comparison matrix, representing whether a positive, negative, or no relation exists between variable pairs, is obtained through feedbacks received from the experts. Based on this matrix, the resulting preliminary map is drawn.

The causal maps provide a visual representation of the concepts of a system. However, it is not possible to model the uncertainties associated with the decision variables and make inferences about the concepts. BBNs offer as a probabilistic approach by identifying the concepts as random variables and causal relationships as conditional dependencies. In BBN, developed as directed acyclic graphical models, the nodes represent stochastic variables and directed arcs represent conditional dependencies between the variables. The required acyclic structure of BBNs does not allow any cycles. The non-directed cycles that do not violate the acyclic structure indicate a dynamic nature to the BBN in which sequences of variables are modeled. In order to maintain the acyclic structure of the BBN, the causal maps are revised through additional interviews with the experts. The cycles are mainly formed due to a dynamic relationship between concepts across multiple time frames. In this case, a part of the edges of a loop belong a former time frame, whereas the others relate to a latter time frame. Experts disaggregate concepts into multi time frames or revisit the nature of relationship between the variables that form a cycle. They are also asked to choose the dominant causal influence when concepts have reciprocal influences. As a result the final causal map is revealed.

The states of the categorical variables yielded directly during specification of the variables. However, the numerical variables such as travel time are transformed into discrete variables before calculating the conditional probabilities (details of discretization are not given because of space limit). The states of the variables together with the number of nodes and links determine the number of conditional probabilities to be calculated (Janssens *et al*., 2006). The prior frequency distributions for the variables are derived from the data. Using the frequency distributions, conditional probabilities are calculated. The final network yields 14 nodes, 20 links and 2335 conditional probabilities in total. When dependencies are specified for the sequences of variables, the computations of the probabilities gets more complex. So, the authors use Netica v4.16 which provides a probabilistic inference algorithm for BBNs. The conditional probabilities of the compiled BBN extracted from the final causal map are given in Figure 1.

The prior distributions given in Figure 1 are useful but more importantly BBNs compute posterior probability distributions of the variables, given the fact that values of some other variables are known. For example, if we know the access mode of the traveler, we can find the posterior probabilities of customer satisfaction levels of performance dimensions. The computation of this case on Netica is depicted in Figure 2. Using the posterior probabilities, predictions for different cases may be obtained. The travel time satisfaction levels for passengers with different access modes are predicted as shown in Table 1.

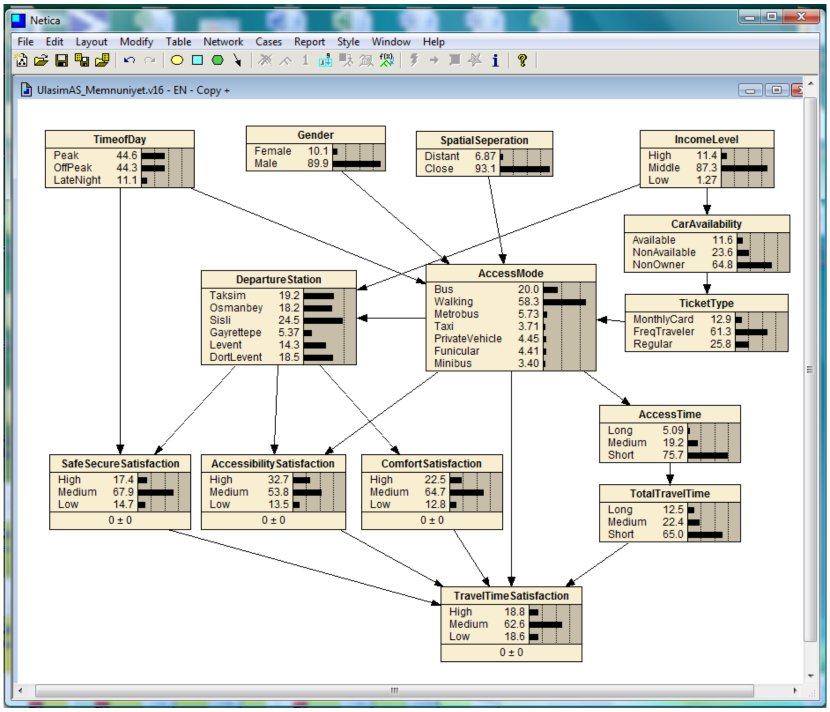

Figure 1 Compiled BBN

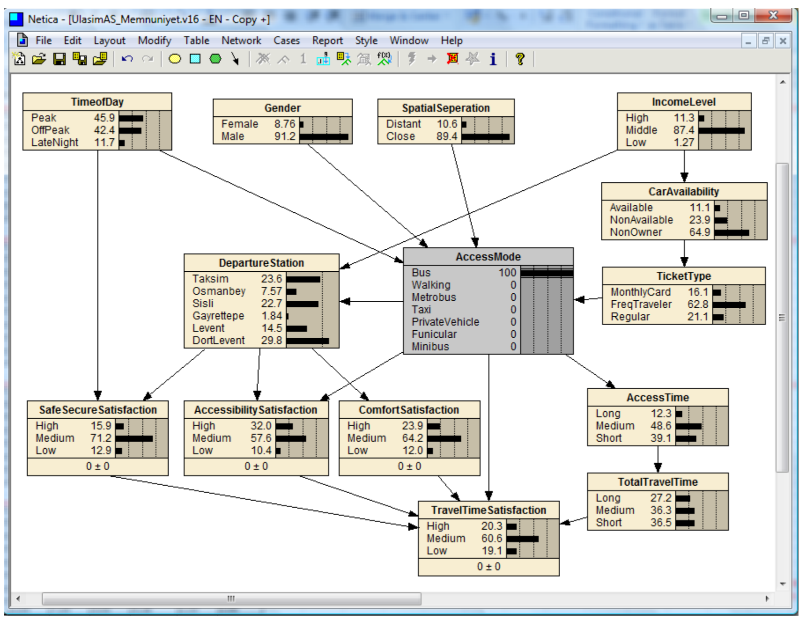

Figure 2 The case where “access mode” is known

The prediction of posterior joint probabilities can also be computed when information on more than one variable is available. For example, posterior probabilities of access mode are observed when the accessibility satisfaction is low, access time is medium and travel time satisfaction is high. The prior and posterior probabilities are compared in Table 2. The highest increase in the probability distribution is observed for metrobus (Bus Rapid Transit) access mode. The change in the beliefs show that even though travelers have a high level of satisfaction when they arrive M2 metro line by metrobuses, the satisfaction level of accessibility related to metrobus access mode is low. In contrast, when the satisfaction level of travel time is high, accessibility is low and access time is medium, the probability of travelers arriving the metro line M2 by funicular and walking modes decrease.

Table 1 Posterior probability distribution of "travel time satisfaction" when "access mode" is known

	Travel Time Satisfaction		
	High	Medium	Low
No additional Information	18.8%	62.6%	18.6%
Access Mode Is Bus	20.3%	60.6%	19.1%
Access Mode Is Walking	14.0%	71.6%	14.3%
Access Mode Is Metrobus	31.2%	39.2%	29.7%
Access Mode Is Taxi	29.1%	41.9%	29.1%
Access Mode Is Private Vehicle	30.8%	39.3%	29.9%
Access Mode Is Funicular	27.9%	44.2%	27.9%
Access Mode Is Minibus	32.3%	36.9%	30.8%

Table 2 Posterior probability distribution of "access mode" when a couple of evidences exist

Access Mode	Prior Probabilities	$P^*(AccSat._{Low}, AccTime_{Medium}, TrTimeSat._{High})$
Bus	20.0%	33.2%
Walking	58.3%	10.5%
Metrobus	5.7%	24.7%
Taxi	3.7%	10.4%
PrivateVehicle	4.4%	6.3%
Funicular	4.4%	3.8%
Minibus	3.4%	11.2%

The developed BBN of the multimodal transportation system is used to analyze the complex conditional dependencies among the variables. The network's visual characteristic allows easy sensitivity analyses by simply changing variable states and observing the automatically updated decision outcomes. As travel time satisfaction is the main performance indicator in the network, sensitivity analysis is done to identify the relative importance of the variables affecting this indicator. The mutual info sensitivity measure shows how much the variable can affect travel time satisfaction. Quadratic score, on the other hand, shows how much information is obtained from observing an event. If travel time satisfaction is more sensitive to an affecting variable, the quadratic score of that variable would be higher. Table 3 shows that travel time satisfaction is most affected by and more sensitive to accessibility satisfaction and access mode.

Table 3 Sensitivity of ''travel time satisfaction'' based on findings at another node

Node	Mutual Info	Quadratic Score
Accessibility satisfaction	5.479%	1.0314%
Access mode	4.759%	0.9749%
Total travel time	1.967%	0.4237%
Safety and security satisfaction	1.699%	0.3688%
Comfort satisfaction	0.981%	0.2111%

3. Conclusions and Further Suggestions

In this study, a BBN approach is used for performance evaluation of multimodal transportation systems. The integrated services offered to travelers are difficult to evaluate due to the interaction among the incomparable variables and the stochastic nature of the system. Bayesian networks allowed to represent and visualize the system and to conceptualize the association between variables. In the final BBN which is developed to investigate the multimodal travels of trunk-and-feeder systems, the most important variable of the multimodal travels is found to be access (feeder) mode. Since the trunk mode is a high capacity and high speed mode, the main performance determinant of the multimodal transportation systems is the performance of the feeder mode. Thus, feeder modes should be carefully planned and integrated to the trunk mode for effective multimodal transportation systems. Besides, in the case study, accessibility satisfaction and access mode variables are shown to be more effective variables than total travel time for travel time satisfaction. This also indicates the importance of access in multimodal travels.

In the case study, it is shown that, detailed predictions regarding the performance of different access modes or stations can be obtained using BBNs. For example, accessibility performance is low for

metrobus and minibus access mode, whereas funicular yields the best performance for accessibility satisfaction. Results regarding preferences are also provided by conducting detailed analysis. For example, it can be shown that gender and ticket type are important variables for access mode choice.
In order to generalize use of the proposed model, future research may investigate differences resulting from the use of local, regional, and national data sources. In such situations, the proposed framework should act as a useful guide for policy-makers in developing strategies to improve the performance of selected transportation systems as well as in the allocation of scarce resources subject to budget and other system priorities.

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