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An urban transportation performance model with spatial structure transit

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Abstract. This research has developed a mathematical model to measure an urban transportation system performance which includes spatial structure. The result shows this method of measuring urban transportation system is also able to be used to project the next step transportation system by changing its variable. To be able to represent each city and its support areas a further research are to be made, including variable related to service.
Keyword: urban transportation, mathematical model, system performance.

1. Introduction

In developing country, urban transportation is crucial part of the solution to the nation's economic, energy, and environmental challenges. Challenges in urban transportation such as traffic congestion, longer commuting time, public transport inadequacy and difficulties for non-motorized transport often are to be tackled to provide better transportation mode option. These challenges are linked to each other which resulted with added complexity within urban transportation system. Urban transportation is highly complex because of the modes involved, the multitude of origins and destinations, and the amount and variety of traffic. Traditionally, the focus of urban transportation has been on passengers as cities were viewed as locations of utmost human interactions with intricate traffic patterns linked to commuting, commercial transactions and leisure/cultural activities. Conceptually, the urban transport system is intricately linked with urban form and spatial structure. In most developing cities, a similar structure is found, which it shows most cities are supported by satellite city or suburban on the outer layer to support millions of city residents.

Urban transportation's challenges such as traffic congestion, longer commuting time, public transport inadequacy and difficulties for non-motorized transport often are to be tackled to provide transportation mode option with higher quality. These challenges are linked to each other which resulted with added complexity within urban transportation system. In order to tackle those challenges and improve the performance of the system a research to build a performance model is needed. In developing country such as Indonesia, fare consistency and on-time performance are not being considered seriously and is suggested to provide more than one general level of transportation services[6]. Meanwhile in urban transportation, the attribute on-time performance and safety at stops are considered influential[5].

In previous research on Transit-oriented development (TOD) and multimodal transportation, it is suggested to use TOD as an effective approach, as key nodes provide accessibility of integrated multi-modal public transportation system. These key nodes or centres are to reduce reliance on automobile (P Mess, 2015). Most of previous research focus on statistical model to understand the perceived image of public transportation performance which resulted with the understanding This research develops a mathematical model of urban transportation which includes integrated multi-modal transportation.

2. Methods

This research develops a mathematical model of urban transportation which includes integrated multimodal transportation, spatial structure and transport interchange. The model is developed into a generic model that represents the actual concept of a city with supporting suburb area, travelling time based performance, service variables. This objective of the model is to maximize performance based on total trips and service rate of each transportation mode. Objective function of this model is to maximize performance:

$$\sum_i \sum_j \sum_l P_{ijl} = \sum_i \sum_j \sum_l \{S_{ijl} \times R_{ijl} \times X_{ijl}\} \quad (1)$$

The model is developed to measure the current development of urban transportation by using transport interchange concept to integrate urban multimodal transportation. Equation (2) is set to limit each mode of transportation by its capacity.

$$\sum_i \sum_j \sum_l R_{ijl} \leq \sum_i \sum_j \sum_l C_{ijl} \quad (2)$$

To incorporate each big city supporting area which are usually used as housing complex for those who work in central are city, a spatial structure is used. Nodes are used to represent the spatial area as shown in Figure 1. Then each node is assigned a number as demand of each area of daily trips which shown in model by variable T. Equation (3) represents transportation demand from each origin to destination, and the failure to facilitate trips demand is shown.

$$\sum_i \sum_j R_{ij} + \sum_i \sum_j F_{ij} = \sum_i \sum_j T_{ij} \quad (3)$$

2.1. Spatial Structure

Each city has its own spatial structure characteristics, in this model a grid based spatial structure is developed as shown in figure 1. Each node represents an origin or a destination of trips. This grid or node contains its attributes of service variable. To apply spatial structure in the model a data of city structure is needed, to represent city center, business district, and housing complex or city support (satellite city, suburb). Within this spatial grid, necessary attributes of trips such as demand, service variables are divined.

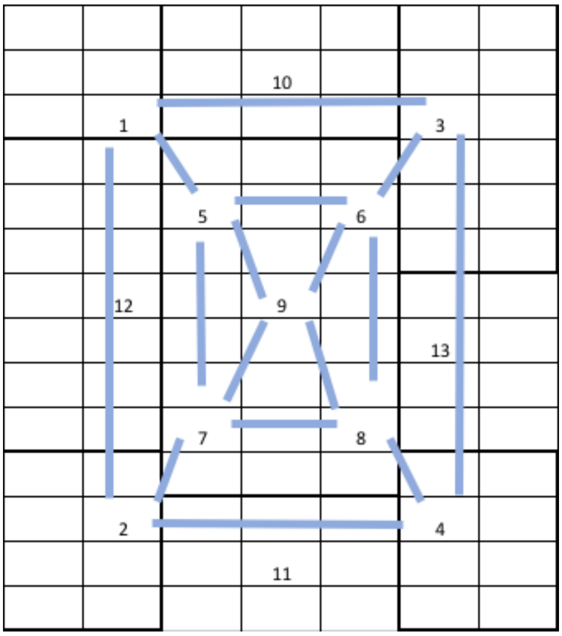

Figure 1. Spatial Structure grid to represent location and nodes for origin and destination of each trip

2.2. Service Variables

Based on previous research, mode selection of each trip is effected by previous experience with resulted with bad service quality rate which is included to be analyzed. This model is aim to maximize the performance value, which to represent the character of transportation user's decision making. Variable S or service from equation is representing the decision making of each user which will choose the comfortable level of each modes.

$$S_{ijl} = \frac{\mu_{ijl} \times \pi_{ijl}}{D_{ijl}} \tag{4}$$

Therefore, an on time and easy access variable is combined, then a dissatisfaction variable is included (D_{ijl}). Services variables are easy access which is translated from accessibility of services, Safety, Reliability as shown in table 1.

Table 1. Service Variables.

Variables	Details	Mean	Weighted Variables
Safety	Vehicle tracing	3,25	0.65
	Safety	4,5	0,9
Reliability	Well-timed arrival	5	1,00
	Precise and reliable information systems	4	0,8
Accessibility of services		4.25	0,85

2.3. Case Study

In this case study four mode of transportation are used, there are Automobile, Train, Bus, On-Demand transportation. Capacity of each modes are set to limit the users within each node. Automobile has high reliability score and accessibility, followed by On Demand transportation, and on last rank are buses and trains. Availability of buses and train are limited which resulted with rank lower on user options. Weighted variables are used to determine which mode is chosen by user then it will be counted as a trip. Demand of trips are from supporting area such as satellite city or suburb as center of the city as the destination.

3. Result and Discussion

The result of trip's quantity as parameter of deciding factor on how user decides to choose transportation modes from their origin point to destination. With service variable attached to the model, it is shown that user will choose a transportation mode with better or high service variable. With capacity variable limits each transportation users then is analysed to measure the ability of current system to fulfil trips demand. Using sensitivity analysis method this model able to show which progress to be made. A case study is analysed to verified the model. It shows a service variable is needed to measure performance of the system. First scenario is to increase road capacity (link between nodes) of automobile, this resulted with less trips using buses and trains. Second scenario, to limit automobile user, buses and trains has more demand than normal scenario. Third scenario, by increase the service variables and reducing dissatisfaction helps to increase demand on buses and trains. These results have shown the relation within model that can be used to reflect user decision making and represent performance model of urban transportation.

To add value and service variables of train and buses, more linked nodes are needed as it will increase the accessibility of each buses and train. Nodes to be developed can be seen by demand on each node from origin to its destination.

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4. Conclusion

This research has developed a mathematical model to measure an urban transportation system performance which includes user decision making process. In order to represent user decision making a service variable is used based on previous research. The model is solved and verified by using Lingo Software. The result shows this method of measuring urban transportation system is also able to be used to project the next step transportation system by changing its variable. To be able to represent each city and its support areas a further research are to be made, including variable related to service.

5. References

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