A STUDY ON SCHEDULE-BASED PUBLIC TRANSPORTATION PLANNING MODEL AND INTEGRATION WITH OTHER TRANSPORTATION PLANNING MODELS

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Abstract— Efficient and reliable public transport systems are essential to promote green growth developments in metropolitan areas. A wide range of advanced public transport systems (APTS) facilitates the design of real-time operations and the management of demand. Traffic performance analysis requires a dynamic tool that allows for emulating the dynamic load of travelers and their interaction with the transit system.

BusMezzo, a dynamic transit allocation and operations model was developed integrating time-based public transportation planning with other transportation planning models to enable analysis and evaluation of traffic performance and service level under various traffic conditions. system and APTS. The model represents the interactions between traffic dynamics, transit operations, and passenger decisions. The model was implemented within a mesoscopic traffic simulation model. The different sources of uncertainty in transit operations, including traffic conditions, vehicle capabilities, dwell times, vehicle hours, and service interruptions, are explicitly modeled. The dynamic route choice model in BusMezzo considers each traveler as an adaptive decision maker. The progress of travelers in the transit system consists of successive decisions that are defined by the need to choose the next element of the road. Evaluations are based on the respective route alternatives and their expected subsequent attributes. Travel decisions are modeled within discrete random utility models. A model for generating non-compensatory option sets and the route utility function was estimated based on a web-based survey.

BusMezzo enables the analysis and evaluation of proactive control strategies and the impacts of real-time information provision. Various experiments were conducted to analyze traffic performance from the perspectives of travelers, operators, and drivers under various retention strategies. This analysis has facilitated the design of a field test of the most promising strategy. In addition, a case study on real-time passenger information systems regarding the vehicle's next arrival time investigated the impacts of various levels of coverage and comprehensiveness. As passengers become more informed, passenger loads are subject to greater fluctuation due to traveler accommodations.

1. INTRODUCTION

Sound that is unwanted or disrupts one’s quality of life is called as noise. When there is a lot of noise in the environment beyond a certain limit, it is termed as noise pollution. Sound becomes undesirable when it disturbs the normal activities such as working, sleeping, and during conversations. It is an underrated environmental problem because of the fact that it can’t be seen, smelt, or tasted. World Health Organization (Report 2001) stated that “Noise must be recognized as a major threat to human well-being”

Noise is normally defined as 'unwanted sound'. A more precise definition could be: noise is audible sound that causes disturbance, impairment or health damage. The terms 'noise' and 'sound' are often used synonymously when purely acoustical dimension is meant (e.g., noise level, noise indicator, noise regulation, noise limit, noise standard, noise action plan, aircraft noise, road traffic noise, occupational noise, etc.). The link between exposure and outcome (other terms: endpoint, reaction, response) is given by a reasonably well-established exposure-response. Managing noise is crucial for enhancing the living conditions of a dwelling. Noise can be generated internally within a building (e.g., noise from surrounding neighbors’ voices, music or appliances) or externally (e.g., traffic noise from automobiles, buses, trains, aircraft, industrial activities or surrounding construction activities). Noises (or impact of sounds) are transmitted through building materials from sound sources such as vehicular or foot traffic, banging, or objects being dropped to the floor and can also be associated with vibrations. The design solutions for limiting air-borne and structure-borne noises are not always the same as stated by Li et al (2000).

Nowadays noise pollution is the focus of various studies and research due to its proven significant impact on human health and work efficiency. Research shows that traffic noise in urban areas has tremendously increased since the beginning of the century, primarily due to increased transportation of people and goods. It can be concluded that in urban areas the largest source of noise is traffic-induced noise, which accounts for 80% of all communal noise sources. Traffic noise caused by road traffic is the most common type of noise in urban areas and as such poses a serious problem.

Figure 1 shows the distribution of human noise annoyance according to the type of noise source [1].

According to Table 1, provided by the International Union of Railways (UIC), all types of trains produce less noise than trucks, cars, airplanes, and other means of transport. Railway is the most favorable form of transport, in terms of noise as an influential factor for environmental degradation and human health. Therefore, it can be determined that the railway has the lowest share of noise in urban areas among other means of transport.

Noise is an environmental problem that poses various negative effects on health and economy, and has increasingly attracted the attention of researchers and engineers in recent years. Studies show that 30% of European Union (EU) citizens are exposed to traffic noise exceeding the acceptable level recommended by the World Health Organization (WHO), with 10% complaining of sleep disturbance at night (Ahammed, 2009). Environmental noise causes various negative effects on human beings, such as cardiovascular effects, rising blood pressure, stress and vasoconstriction increasing, and increasing risk of coronary artery diseases. In Denmark, about 800 to 2,200 people are admitted to hospitals annually with high blood pressure or heart disease and 200 to 500 die prematurely which are considered to be associated with high levels of traffic noise (FEHRL 2006).

The tire/pavement interaction noise has been proven to be the major source of the traffic noise, especially for cruising driving conditions (Sandberg and Ejsmont, 2002). The research proposed by de Graaff and van Blokland (1997) indicated that about 90% of the equivalent sound energy in urban traffic is generated by tire/pavement interaction. Consequently, the reduction of tire/road noise can be an efficient way for traffic noise mitigation. Road re-pavement has been a method applied for traffic noise reduction. The noise reduction mechanisms by the pavement itself include acoustic and mechanical impedance, in which the acoustic impedance depends on the surface characteristics (i.e. porous or non-porous), and the mechanical impedance is related to the relative stiffness of the tire and pavement (Neithalath et al., 2005; Ahammed, 2009). The steady growth in population, motorization and demand causes great traffic problems, mainly in large metropolitan areas. Transport authorities focus on more effective utilization of existing transport infrastructure by applying operation strategies and demand management schemes. It is well recognized that transit systems have a pivotal role in developing more sustainable and efficient transport systems. Consequently, the improvement of transport services and management is one of the foundations of the Indian transport policy (Indian Commission for Transport, 2019). An important challenge facing transport policy makers and planners is to design attractive alternatives to the private car. These efforts focus on improvements in terms of door-to-door times, reliability and comfort while at the same time minimizing operating costs.

An additional policy priority that targets the need for more efficient transport system is the further incorporation of intelligent transportation systems (ITS). ITS include a large range of such applications, among them electronic toll payment, traveler information and freeway management. The development of advanced technologies for transport systems also contributes to the improvement of transit systems. The set of ITS that is aimed at improving transit performance and level of service is known as advanced public transport systems (APTS). APTS are generally classified into four categories of systems: fleet management, traveler information, electronic payment, and demand management. Instantaneous data collection and communication technologies enable the design and application of real-time monitoring and control schemes. The implementation of these schemes has the potential to improve transit performance and level of service. An example of an APTS application is the provision of real-time arrival information at stops based on automatic vehicle location (AVL) systems, which provide passengers with real-time departure information. The implementation of AVL systems also supports applications of various schedule monitoring techniques (such as holding, skipping and dispatching decisions) and transit signal priority (TSP) schemes. The Federal Transit Administration reports that APTS implementation increased by over 70% between 1995 and 2000 (FTA, 2000). The intensified adoption of APTS calls for methods that will represent their operation and passengers' response to them in order to evaluate them and refine their design.

Long-term strategic transport planning is typically based on the classic four steps model. The conventional four steps model was extended and revised in recent years to accommodate activity-based modeling and trip departure choice (Ortuzar and Willumsen, 2001). The four-step planning model is aimed for strategic planning and policy making and has to take into account long-term processes as land-use development, socio-demographic trends and future infrastructures and services. There are several commercial packages that are commonly used for predicting traffic and transit conditions based on the four-step models (e.g. TRANSCAD (Caliper Co., 1996), EMME/2 (INRO, 1999), VIPS (VIPS, 2000)). These models are useful for long-term planning, where the input is approximated and the output is interesting at the network-wide aggregated level. However, those models are not suitable for mid- and short-term transit planning and operation analysis, where the dynamic evolution of system conditions is the main interest.

2. LITERATURE SURVEY

Traffic assignment models constitute the forth class of models in the classic four-step transport forecasting process (Ortuzar and Willumsen, 2001). The assignment follows the phases of trip generation, trip distribution and mode choice. Traffic assignment models take the mode-specific travel demand OD matrix and distribute it over the transport network by assigning trips to routes. Similarly, the transit assignment problem is concerned with how flows are distributed over transit paths on a given transit network for a given OD travel demand. The interaction between travel demand and transit network supply determines the transit system's performance. Therefore, the core of any assignment model is a route choice model. The route choice model links passenger decisions with network conditions based on user preferences and service characteristics. The process of assigning passengers to transit paths requires the modeling of passenger perceptions and travel behavior.

TAM loads transit passengers on a given transit network to obtain passenger loads and the level-of-service. Hence, it is a fundamental analysis and evaluation tool at both planning and operational levels. Subsequently, much research effort was devoted to the development of TAM in the last few decades. Many of those modeling attempts adopted ideas from general traffic assignment models and tried to adjust them to transit network conditions. However, several characteristics of transit systems introduce additional complexities to the car traffic assignment problem. The main reason for greater complexity is the discontinuous availability of transit supply both in space and time. This is especially evident in the case of transfer connections with temporal and spatial constraints. Hence, the importance of modeling walking and waiting times. An additional complexity arises from the relationship between service uncertainty, passenger loads, comfort, travel times and capacity constraints. Furthermore, most transit networks consist of several modes with distinguished sub-networks. These networks exercise different levels of interaction with car traffic (Nielsen, 2000; Wahba and Shalby, 2005).

Traffic assignment models are commonly classified based on their deterministic or stochastic equilibrium conditions and their static or dynamic loading procedure. Likewise, these classifications also apply to transit assignment models. A static representation and loading process of the transit system could be justified in case of long-term planning applications. However, static assignment models neglect the evolution of network conditions, time-dependent interactions and en-route user decisions.

Conventional TAMs are static equilibrium assignment models which are insensitive to service disturbances, the effects of information, and incidents. The following presents the two classes of conventional transit assignment models: frequency-based TAM (FB-TAM) and schedule-based TAM (SB-TAM). This classification is based on the representation of the transit network as it has substantial impacts on the passenger loading procedure. FB-TAM represents of the transit network at the line-level with the corresponding frequencies, while SB-TAM includes a more detailed representation of the time-dependent specific vehicle runs (Lam and Bell, 2003; Ceder, 2007). A review of the state-of-the-art FB- and SB-TAM developments is given in the following sections.

Early attempts to propose TAM were based on applying user equilibrium (UE) conditions to transit networks (Dial, 1967; Le Clercq, 1972). These algorithms did not consider the common lines problem – how passengers are distributed between several lines that compose the trunk-line link. In a review of operations research methods applied to public transport problems, Desaulniers and Hickman (2007) list three main challenges in the determination of the minimum cost path: time-dependent stochastic attributes; path definition and its compatibility with the common lines problem and; impacts of capacity and discomfort.

A probabilistic framework for this problem was presented by Chirqui and Robillard (1975) assuming that passengers board the first arriving vehicle that belongs to a set of attractive lines. Marguier and Ceder (1984) extended the analysis of the common lines problem by considering the influence of bus regularity and passenger arrival process.

An important advancement in the field of transit path choice was the result of studies by Nguyen and Pallottino (1988) and Spiess and Florian (1989). Spiess and Florian defined travel strategy as a set of rules that when applied, allow the traveler to reach his or her destination. Their optimal strategy model minimized the total travel time which is composed of access, waiting and in-vehicle time. It is still assumed that passengers board the first arriving bus from the attractive set of transit lines. The attractive set includes all the lines whose riding time is not longer than the expected total travel time of the remaining lines in the set. The latter is calculated as a weighted average by considering the line probabilities to split proportionally to the frequencies, regardless of their riding time. The transit equilibrium model was formulated as a mixed integer program with an objective function of total travel time. The problem included flow constraints and non-negativity constraints. They were the first to transform the problem into a linear programming problem. Nguyen and Pallottino presented a graphic representation for the transit loading procedure. A hyperpath was defined as an acyclic directed graph from origin to destination that results from performing a strategy. The share of passenger flow using each outgoing transit link is proportional to the corresponding frequencies on the hyperpaths so that flows can be calculated backwards, starting from the destination.

3. DYNAMIC TRANSIT MODEL FRAMEWORK

The performance of transit systems is a result of complex interactions between various system components. A dynamic perspective allows analyzing the way that system components evolve over time and their interactions under various conditions. This chapter is organized as follows: First, the components that have to be represented in order to capture transit system dynamics are discussed. Sections 3.2 and 3.3 elaborate on the modeling of traffic dynamics and transit operations, respectively. The different levels of demand representation are outlined in Section 3.4 as chapter 4 is devoted to the development of a detailed dynamic passenger model. Section 3.5 presents how these model components are integrated within the simulation model framework.

A. MODEL COMPONENTS

Transit systems consist of various components that interact through several processes. Following the objectives of this study, the core of the model consists of three main components: traffic dynamics, transit operations, and traveler decisions (Figure 3.1). Modeling these components involves the dynamic movement of cars, transit vehicles in mixed networks (e.g. bus, light rail, metro), and transit users. Each agent in the system carries out decisions, interacts with other agents, and so affects the way the system evolves over time. This modeling approach is sometimes referred to as agent-based modeling (e.g. Salvini and Miller, 2005; Ettema et al., 2007). For example, traffic conditions that result in high travel time variability are associated with a reduction in transit service reliability. This, in turn, will affect transit users' waiting times and crowding levels at stations and on board. While the interactions between system agents are specific in time and space, the accumulated impacts of those interactions along transit lines and service times are not. Therefore, the modeling of transit systems also has to consider the evolution of the system over time at the network level. Hence, the developed model aims at analyzing transit systems at the network level.

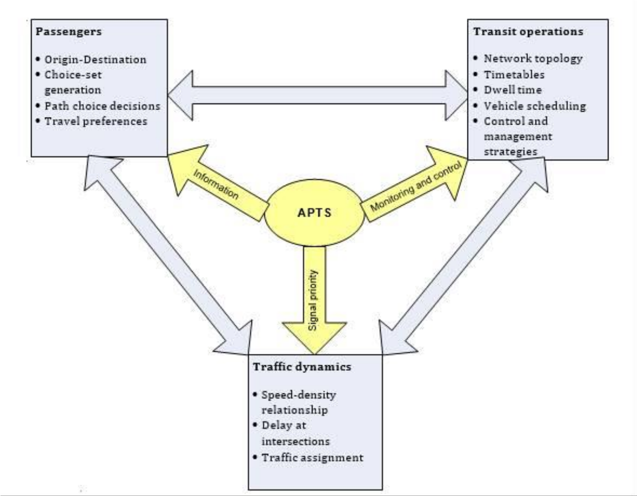

Figure 3.1: Transit model components

APTS applications can affect the performance of transit system components. Control and information technologies are utilized for improving transit performance and the dissemination of real-time information (RTI). Real-time control strategies may regulate the service by enforcing transit signal priority (TSP) or holding strategies. Travelers may make different decisions based on their experience and the information available to them at various stages along their journey. The following sections describe how each of the above components is represented in the model.

B. TRAFFIC DYNAMICS

Most transit services travel on mixed-traffic networks where traffic dynamics influence their performance. The interaction occurs both along road segments as well as at intersections. The level of traffic dynamics representation has to be on one hand detailed enough to allow the modeling of local interactions (e.g. at stops or intersections) and on the other hand general enough to enable large-scale applications. Therefore, an intermediate ('mesoscopic') level of representation with regards to traffic dynamics was adopted in this model.

C. MEZZO

Mesoscopic traffic simulation models represent traffic dynamics at an intermediate level between microscopic models and macroscopic models. Macroscopic models represent traffic at an aggregated level based on flow-density functions without representing lanes or vehicles. In contrast, microscopic models represent traffic at a detailed level with explicit driving behavior characteristics of individual vehicles, such as lane changing, acceleration and gap acceptance. There is an inverse relationship between the level of detail and the computational effort that the model requires and hence its applicability to large-scale networks. Mesoscopic models offer a compromise between these two aspects by providing a useful trade-off between the level of detail on one hand and the ability to analyze at the system-wide level on the other hand. Mezzo represents individual vehicles, but models their progress in the network through speed-density relationships. This level of representation allows modeling the propagation of congestion dynamically as well as route choice decisions while avoiding the detailed modeling of vehicles' second-by-second movements.

The transit simulation model is built within the platform of Mezzo, a mesoscopic traffic simulation model (Burghout et al., 2006). Mezzo is an event-based simulation model that incorporates an iterative dynamic traffic loading procedure. De Palme and Marchal (2002) argued that a mesoscopic simulation with an event-based architecture can outperform time-based microscopic models by one or two orders of magnitude in terms of computational time. An overview of the traffic modeling in Mezzo is presented next. A complete description of the structure of Mezzo and its implementation details are presented in Burghout (2004).

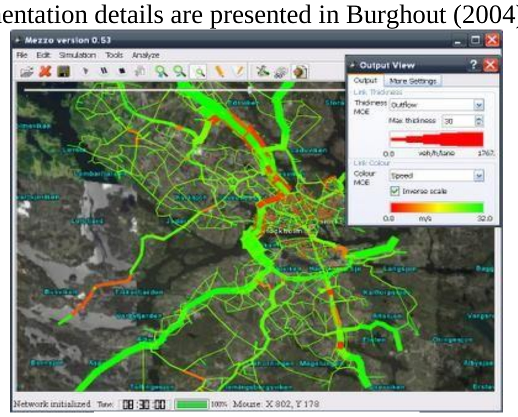

Figure 3.2: Mezzo GUI screen

SPEED-DENSITY RELATIONSHIP

Links in Mezzo are divided into two parts: a running part, which contains vehicles that are not delayed by the downstream capacity limit; and a queuing part, which extends upstream from the end of the link when capacity is exceeded. The boundaries between the running and queuing parts are dynamic and depend on the extent of the queue. Vehicles enter the exit queue in the order they complete their travel in the running part. The earliest exit time is calculated based on the speed, which is a function of the density in the running part only. Travel times on the running part are determined by a speed-density function.

In the following sections, a more detailed explanation on how electric vehicles affect the reduction of noise levels will be provided, especially in urban areas. On the other hand, problems that occur with electric cars will be discussed. In addition, the effect of smart traffic management system, traffic behavior changes, and quiet road surfaces in terms of noise reduction will be examined.

4. DYNAMIC PATH CHOICE MODEL

The previous chapter presented the framework of the transit simulation model. It provided an overview of the mesoscopic traffic dynamics modeling and described the main modeling components involved with the representation of transit operations. The core of the transit operations modeling capabilities was developed and discussed in my master's thesis (Cats, 2008) and related papers. The supply side of the transit system will be further discussed in the context of transit performance analysis and the evaluation of control strategies in Chapter 6. The following chapters discuss the modeling of the demand side – the dynamic loading of travelers in the transit system.

A. TWO-STAGE MODELING

The modeling approach adopted in this thesis is to represent the transit path choice as a semi-compensatory two-stage choice process. Figure 4.1 illustrates the two-stage approach that is applied in this study. The first phase is a non-compensatory rule-based choice-set generation model (CSGM). The deterministic generation process is based on network configuration (lines, stops) and the corresponding timetables, which specify trip departure times and expected travel times. It results in a path set for a given OD pair of locations in the network. The path set is given as input to the probabilistic dynamic path-choice model (DPCM). The simulation model, BusMezzo, generates individual travelers who undertake successive path choice decisions that are triggered by the evolving transit system conditions (e.g. vehicle arrival). The evaluation of alternative actions (e.g. board vs. stay) depends on traveler's preferences and the traveler's expectations. The latter are determined by prior knowledge and the availability of real-time information (RTI). Traveler's ability to carry out his/her decision is subject to vehicle capacity constraints.

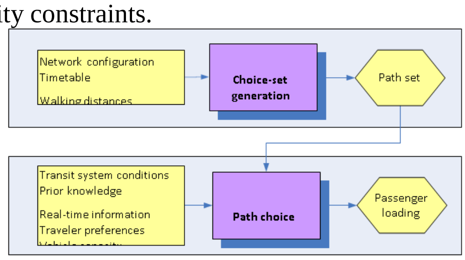

Figure 4.1: Two-stage modeling approach

The CSGM could be applied dynamically by generating the time-dependent path- set upon making a path decision. This allows a consistently adaptive approach of the path decision process. Alternatively, Bovy (2009) highlighted the theoretical and practical advantages of specifying the choice set as a preliminary phase. Among those advantages, he listed the higher adequacy when dealing with overlapping as well as the large savings in computational effort as the exhaustive choice-set generation phase is performed once. The generation of an intermediate choice set avoids the enumeration of all path alternatives for each traveler choice. The generated choice-set is aimed at reproducing the set of alternatives that are considered by travelers when carrying out their trip.

The CSGM is currently implemented in BusMezzo as an initial phase. It results in a path-set for each pair of locations in the network that is given as input to the DPCM. However, there is no limitation to modify the simulation model so that the CSGM would be applied dynamically.

The OD matrix can be composed of elements of different natures. Distances between geographical locations can be specified or obtained from a GIS tool. Travelers can initiate their transit trip at various stops subject to their path choice decisions by travelling between connected spatial points (e.g. stop-stop, anchor/centroid-stop). Note that the CSGM takes into account the connections between the origin and the first stop and between the last stop and the destination. This modeling approach allows having an OD matrix that refers to key locations such as transit hubs or urban landmarks without having to specify generation rates at the stop level. It has the advantage of modeling travelers' distribution over the relevant stops through the execution of the DPCM in addition to its advantage in terms of data requirements. The model allows the specification of a connection between each pair of spatial points in the network, regardless of their characteristics. This property avoids the limitation induced by the hierarchal structure used in existing transit assignment tools (e.g. nearby stops that belong to a neighboring TAZ are inaccessible due to arbitrary cut offs).

5. CONCLUSION

The evaluation of RTI requires the dynamic modeling of transit supply and demand. A framework for modeling RTI was presented and implemented in BusMezzo, a transit simulation model. The simulation of individual transit vehicles and travelers enables to modeling the generation, dissemination and influence of RTI on passenger choices. Each traveling decision is based on the anticipated attributes of path alternatives. Travelers' anticipation depend on the information that is available to the passenger when making the decision, either from location-based displays or individual access to RTI through personal mobile devices.

This model was used as an evaluation and analysis tool for case studies based on Stockholm network. The CSGM composed all reasonable paths and the DPCM processed passenger decisions under various operational conditions and RTI provision scenarios. The results indicate that providing more comprehensive RTI has the potential to lead to path choice shifts and time savings. The analysis also suggests that significant benefits can be achieved by simple improvements in transfer coordination.

The analysis of RTI impacts can be used as part of an economic assessment of RTI system installation. The evaluation can support decision makers in prioritizing locations and attributes of the displayed information since the coverage of this systems is typically limited to certain stations or services. Furthermore, the model can be used as a test-bed for various methods to generate RTI based on transit performance predictions. The arrival prediction model used in this study could be enhanced to incorporate real-time predictions of downstream traffic conditions and passenger volumes.

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