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INTEGRATED LARGE-SCALED URBAN SIMULATION SYSTEM FOR THE BANGKOK METROPOLITAN AREA

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ABSTRACT

Because today's urban systems have become so complex, making decisions for their design changes or additions to address issues such as traffic congestion, land use planning, social behavior and environmental pollution is very difficult. Moreover, available tools in the present do not provide enough information for making such decisions accurately and effectively. This paper proposes new integrated modules utilizing the parallel and distributed computation which provide the ability to study large-scaled structures. They are developed using the activity-based model, agent-based micro-simulation, and the Constrained Cellular Automata approach. These integrated modules will simulate dynamic details in the complex urban systems and provide results to support decision makers so that better and more efficient plans can be made. The modeling system emphasizes on the transportation network in Bangkok's metropolitan area, where the network structure is not well-organized and the driving behaviors are not systematic.

1 INTRODUCTION

Complex urban transportation systems are stochastic and dynamic in which traffic behaviors change over time. The present and future states of the systems also interrelate and affect the behaviors, making it impossible to obtain closed form analytical system representation. To represent such a system, simulation techniques are commonly employed. However, a simulation for unpredictable behaviors requires complex decision rules for each individual in the system to accurately provide sensitivity analyses such as the effects of changes in gasoline prices, tolls, bus fares, and traffic congestion, which are key features in transportation planning. Hence, we are developing a transportation simulation system that captures individual traffic decisions in details for the sensitivity analyses. The new system is composed of several integrated modules which simulate various dynamic details. This paper describes these modules and proposes a modeling methodology applicable for the traffic network in Bangkok, Thailand, where the transportation structure is not well-organized and the driving behaviors are not systematic.

2 LITERATURE REVIEW

Traffic flow models used in traffic engineering can be classified into three categories: *macroscopic*, *mesoscopic* and *microscopic* (Banks 2002). Macroscopic models or aggregate models describe the relationships among traffic speed, flow, and density. Microscopic models or disaggregate models trace movement of vehicles and their interactions. These models include car-following models, gap-acceptance models, and lane-changing models. Mesoscopic models fall in between microscopic and macroscopic models.

Widely used traffic flow models are macroscopic models based on the four-step procedure developed in 1950s. The four steps include trip generation, trip distribution, mode choice, and trip assignment. The trip generation produces traffic volume as a function of household demographics and land uses. The trip distribution pairs origins with destinations. The mode choice assigns means of traveling for each pair of origin and destination using a utility function. The trip assignment determines routes used by travelers. This four-step model is an aggregate model which determines the number of trips in a geographical zone from their characteristics and number of population living in that zone. The model simplifies the uniqueness of individual preferences benefiting in quick computation. It, however, does not permit detailed analyses of model results such as the behavioral responses to changes in traffic policies. In order to capture more details for transportation planning and analyses, a disaggregate model, in which every vehicle and person is individually traced, is needed.

Microscopic models are difficult to analyze analytically, leading to the utilization of simulation technology in micro-simulations to provide better and faster results. There are more than 50 micro-simulations that deal with traffic management problems on road network (Algers, Bernauer et al. 1997). The simulation procedures of these models follow either the time-stepping approach or the event-based approach. The vehicles are moved around the network using a fixed time step in the time-stepping approach. For the event-based approach, the states of vehicles in the network are changed according to the events in the event list. In micro-simulations, signalized and unsignalized intersections can generally be modeled. Traffic queues can also extend to upstream link and obstruct traffic flows. Additionally, both adaptive and coordinated traffic signal systems are modeled as an integral part of the simulators, as special signal control programming languages, or as external modules.

From the survey studied by the SMARTEST project (SMARTEST 2000), the functionality of micro-simulations should include abilities to model incidents, public transport stops, roundabouts, commercial vehicles, bicycles and motorcycles, pedestrians, High Occupancy Vehicle (HOV) lanes, varying lane widths, operations of toll plaza on freeways, detailed driving behaviors, and roadside parking. They should also provide the Intelligent Transportation System (ITS) modeling ability which allows analysts to conduct studies on adaptive traffic signals, coordinated traffic signals, priority for public transport vehicles, vehicle detectors, ramp metering, variable message signs, incident managements, dynamic route guidance, freeway flow controls, and variable speed limits. The performance of micro-simulators should be several times faster than the actual time. Micro-simulators should also run on personal computers and their integrations with databases and Geographic Information Systems should be simple. Statistical information from micro-simulators should include efficiency indicators, safety indicators, comfort and stress indicators, and technical performance indicators. The efficiency indicators include travel time, congestion, travel time variability, queue lengths, speed, and public transport regularity. The safety indicators include headway, interaction with pedestrians, overtaking maneuvers, number of accidents, speeds at which accidents occur, and time-to-collision. The environmental indicators include exhaust emissions, roadside pollution, heat, and noise level. The comfort and stress indicators include stress, and physical comfort. The technical performance indicators include fuel consumption, and vehicle operating cost.

These micro-simulations can be classified by traffic situations used in the models: Urban model, Freeway model, Combined Urban and Freeway model, Automated Highway System model, and other models. Because the demand distributions of urban street network and of freeway are highly tied together, the Combined Urban and Freeway model is used more extensively. Some of these micro-simulations are CORSIM, VISSIM, MITSIM, and TRANSIMS.

The best-known Combined Urban and Freeway micro-simulation model is CORSIM, which was originally developed by the Federal Highway Administration of the USA in 1960s (FHWA 1996). CORSIM was designed to evaluate the alterations of freeways and urban streets. It simulates traffic and traffic control systems using commonly accepted vehicle and driver behavior models. CORSIM combines two of the most widely used traffic simulations, NETSIM for urban streets, and FRESIM for freeways.

Another widely used micro-simulation is VISSIM, which is a time-stepping behavior-based multi-purposed traffic simulation program. This simulation was developed in Germany during the early 1970s. VISSIM can analyze the full range of functionally classified streets and the public transportation operations. The model consists of two primary components: simulator and signal state generator. The simulator generates traffic which can be viewed graphically. VISSIM also provides the graphical network builder (Bloomberg and Dale 2000). Even though links are used in the simulator, VISSIM does not have a traditional node structure. The signal state generator permits the user to analyze the impacts of signal operations. Based on the time-step detector information from the simulator, the signal state generator decides the status of the signals displayed during the subsequent time step.

MITSIM is another well-known advanced micro-simulation for transportation developed at Massachusetts Institute of Technology (MIT) in 1990s (Yang and Koutsopoulos 1996). The main elements of MITSIM are network components, travel demand and route choice, and driving behavior. The network components consist of road networks, traffic controls and surveillance devices. MITSIM simulates individual vehicle movements using car-following and lane-changing models, as well as traffic signal responding logic. A probabilistic route choice model is used to capture drivers' route choice decisions in the presence of real time traffic information provided by route guidance systems.

TRANSIMS is an integrated combination of travel forecasting, routing module, and micro-simulator. It has been designed to provide transportation engineers with accurate and comprehensive information on traffic impacts, congestion, and pollution (Barrett, Beckman et al. 2002). The Los Alamos National Laboratory (LANL) initiated the implementation of TRANSIMS as a part of the Travel Model Improvement Program sponsored by the U.S. Department of Transportation, the Environmental Protection Agency, and the Department of Energy. The micro-simulator in TRANSIMS is one of the most advanced microscopic traffic simulations because it uses *cellular automata* (Wolfram 1994) to speed up the computational simulation time. The road networks are divided into cells. The number of cells each vehicle occupies is based on the cell size and the vehicle size. The simulator traces individual vehicle movements second-by-second using the car-following model and the lane-changing model (Nagel and Schreckenberg 1992). In addition, it also uses *parallel computing* technology where the networks are partitioned into small pieces and distributed to each available computer (Nagel and Rickert 2001). This allows transportation engineers to study regional models which are not available in the other simulators.

3 MODELING METHODOLOGY AND IMPLEMENTATION

In order to allow transportation engineers to construct regional models with the detailed Sensitivity Analysis (SA) for a metropolitan area, disaggregate models that utilize parallel and distributed computing technology are the feasible choice. In disaggregate models, observations are made in the level of individuals where their daily activity plans are traced second-by-second as well as their behavioral responses to changes in public policies or network structures. Population demographics such as age, sex, and income for each individual are needed to conduct the detailed analysis. This information can be synthesized from existing population databases for Bangkok from the Department of Land Transport, the Bangkok Metropolitan Administration, the Excise Department, and the Royal Thai Survey Department in Thailand. Once the base year population has been synthesized, it must be updated to truly represent the future population. These updates include the aging, births and deaths, marriages and divorces, migration, changes in educational levels, changes in employment statuses, and changes in automobile holdings (Miller 2002).

An activity-based disaggregate model is chosen to represent individual's behaviors within this simulation system. The system consists of many modules responsible for different tasks. The Activity-Matching module assigns common daily activities from the survey, such as work, shopping, and recreations, to each individual based on their characteristics. This module also determines the locations to perform activities and the preferred mode of traveling among them. The Dynamic Trip Assignment module computes the combined routes for each trip among these locations corresponding to specified modes of traveling (Barrett, Jacob et al. 2001). The disaggregation of the model also allows the Dynamic Trip Assignment module to evaluate the utility function of each traveler based on the specified parameters and preferences. The Agent-Based Micro-Simulator module is composed of collections of synthetic, autonomous, and interacting objects or agents. It generates network performances by simulating the movements of the agents second-by-second. This module is used to simulate mobile entities such as travelers and vehicles. Each agent contains the attributes that govern its behaviors. The attributes for travelers are, for example, age, income, sex, educational level, and activity list. The attributes for vehicles are, for example, type, made, capacity, occupancy, speed, acceleration, and route. Agents can exchange information, such as turn signals and speed, among themselves as well as with the environments. Output data from the Agent-Based Micro-Simulator module are supplied to the Operative modules such as the Emission module, the Epidemiology module, and the Land Use module, which transform the data into practical statistics. Figure 1 depicts these modules within the Integrated Large-Scaled Urban Simulation System. It also includes the input data which are network data, land use data, and etc. The system manages all output data from each module with a database system. The Control module selectively feeds data from the database system into the other modules to dynamically recalculate the output data.

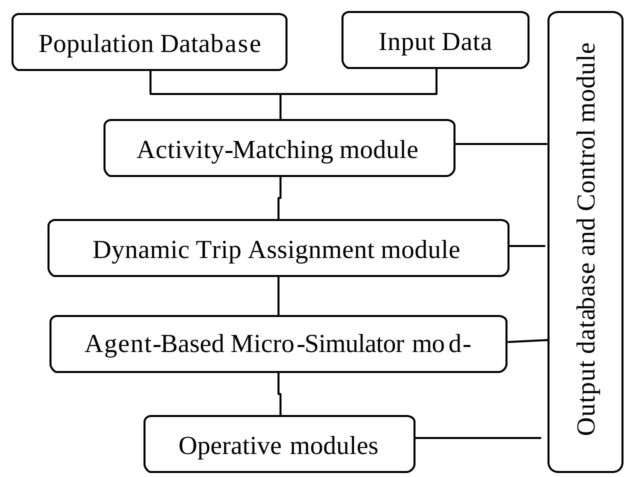

Figure 1 : The flow-chart of the information interaction of each module in the Integrated Large-Scaled Urban Simulation System.

To measure regional network performances accurately, the data for the Operative modules has to be collected second-by-second. This is computational intensive, especially for the large-scaled network structure in Bangkok metropolitan area. Therefore, the Agent-Based Micro-Simulator module will be run in a parallel computing environment. It will also address some unique issues arisen in Bangkok. These issues include driving behaviors of travelers who do not follow the rules such as driving on shoulder. Example statistics are shown in Table 1, 2 and 3. These numbers are significant in Bangkok and none of other micro-simulators account for these behaviors. There is also often bumper-to-bumper traffic congestion which, in the car-following and gap acceptance models, stops traffic flows resulting in unrealistic waiting time for vehicles that are trying to get into the streets. Moreover, the Agent-Based Micro-Simulator module will include motorcycles which account for more than 40% of all vehicle types in Bangkok area (DLT 2003). Movements of these motorcycles tend to violate many models currently available.

Table 1 : Average numbers of vehicles per hour changing lane with different gap conditions on a three-lane outbound freeway in front of Major Cineplex at Rangsit during rush hours. The traffic flow is approximately 5,000 vehicles/hour.

Gap conditions to change lane	With no front gap	56
	With no rear gap	80
	With no front and rear gap	6

Table 2 : Average numbers of vehicles per hour driven on a shoulder of a four-lane outbound street in front of Major Cineplex at Rangsit during rush hours. The traffic flow is approximately 5,500 vehicles/hour.

Type of vehicles	Cars	444
	Motorcycles	136

Table 3 : An average number of jaywalkers per hour in front of Major Cineplex at Rangsit Mall during rush hours.

Number of jaywalkers (person)	1,308

To represent Bangkok's complex network infrastructure, territory, environment, land use, traffic signals, sensors, and other static entities, Constrained Cellular Automata model is utilized. Constrained Cellular Automata is a more complex version of Cellular Automata that contains some combination of a large number of states per cell, complex transition rules, neighborhood interactivity, boundary condition, or initial condition (White, Engelen et al. 1997). Object-Oriented Programming (OOP) is a suitable technique as an implementation tool for our system due to its structure and ability to handle complex systems. Every object in an object-oriented simulation can be mapped to real world objects being studied, giving conceptually better relationships and more apparent solutions to the problems and providing flexibility to the agent-based model. C++ is chosen as the programming language for this project because of its ability to be object-oriented, good memory management, and fast speed. Parallel computing will also be utilized for this large-scaled micro-simulation for faster processing.

Our system consists of two components, urban and expressway. The urban component of the model will be validated against observed data which include travel time, delays, stops, queue lengths, and saturated flows in some metropolitan streets of Bangkok. For the expressway component, the validation will be against the data which include flow and speed distributions, lane usages, lane change rates, and headway distributions taken on Bangkok's expressways. The system will be calibrated with acceleration, deceleration, and gap acceptance for different vehicle types. The animation of the traffic and pedestrians, and the graphical network builder will also be implemented.

4 CONCLUSIONS

To model the Bangkok traffic system, which is a large-scaled problem, we employ activity-based modeling, agent-based micro-simulation as well as Constrained Cellular Automata. We also need to utilize the parallel computing technology to speed up our system which simulates a population of 10 millions (BMA 2003) in the metropolitan area of Bangkok. Our model can be validated and calibrated against the existing statistics available from Thai governmental agencies. Transportation planners and policy makers will benefit from this model which allow them to conduct detailed analyses of Bangkok transportation system.

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