

ABSTRACT

OPTIMAL ADAPTIVE SIGNAL CONTROL FOR DIAMOND INTERCHANGES USING DYNAMIC PROGRAMMING

Fang Clara Fang
The Penn State University

Dissertation Committee

Dr. Lily Elefteriadou (Advisor)
Dr. Konstandinos Goulias
Dr. Martin Pietrucha
Dr. Natarajan Gautam

The signalization of two closely spaced intersections in interchanges presents a major challenge in providing efficient traffic operations within the highway system. PASSER III is the only existing signal optimization model for diamond interchanges, but it provides an optimal solution among a restricted number of alternatives and may not provide the globally optimum solution. PASSER determines the signal plan for a pre-timed diamond interchange and also serves as the optimization algorithm for SMART that was developed as an adaptive control system. However, SMART cannot respond to traffic patterns that change rapidly because it doesn't use advance traffic information. Hence, there is a need to develop an optimal strategy for adaptive control of diamond interchanges.

This research aims at developing a methodology and the corresponding implementation algorithm to provide optimal traffic adaptive signal control of diamond interchanges. Dynamic programming (DP) is applied as optimization method in this research because it offers great computational savings over exhaustive enumeration to find the best combination of phase sequencing decisions from a large number of alternatives. The DP algorithm provides global solutions to both phase sequence and phase duration, which will be a new contribution in the field of real-time signal control.

Due to the operation complexity of signalized diamond interchanges, a combination of several performance measures (such as delay, queues, etc.) is considered in the optimization algorithm development. Moreover, microscopic arrival-discharge models that provide more reliable vehicle information for the optimization algorithm are examined, modified as appropriate, and used in this study. AIMSUN, a stochastic micro-simulation model, will be used to evaluate the DP algorithm and the results will be compared to other signal optimization models using pre-selected performance measures.

The research combines advanced control, sensing, computing, traffic operations modeling and simulation. It contributes to advanced signal control in the context of transportation operations and intelligent transportation systems (ITS). The successful development and implementation of the proposed adaptive signal control will demonstrate the effectiveness of integrating a variety of technologies (i.e., loop detectors, communications infrastructure, real-time optimization and process, etc.) into a single control system to reduce delay and queues, and improve the efficiency at signalized diamond interchanges.

ABSTRACT

**A Microsimulation Model of Activity Patterns and Within
Household Interactions**

Ondrej Pribyl

The Pennsylvania State University

Dissertation committee:

Dr. Konstadinos G. Goulias (Chair)

Dr. Martin T. Pietrucha

Dr. Paul P. Jovanis

Dr. Evelyn Thomchick

The ultimate goal of the modeling attempts in the field of travel demand analysis is to estimate the volume of traffic on particular roads in a transportation network. Recent policy actions (introduction of new technologies, taxation and pricing of congestion) and market trends (market penetration of mobile telecommunication technologies) are also motivating the study of impacts not only on traffic volumes but also car ownership, trip consolidation into chains, departure times, and more general shifts in spatial and temporal aspects of travel demand. For this reason, much effort has been dedicated to create models that would address travel behavior in a more comprehensive way looking at schedules of activities to assess the impact of policy actions. The required precision and level of detail of such models has also changed dramatically over the years. An estimate of only daily volumes was sufficient in the early stages of modeling and regional simulation. However, the current objective of research is to find a model that would estimate the traffic volume virtually at any time instant. It is clear that this is not an easy task and that the original model (UTPS) developed in early 1950s is not sufficient (discussion of its limitations is provided in Part I of this proposal).

A way to overcome these limitations is by using activity-based approaches to travel demand analysis. The idea behind these approaches is that travel demand is derived from demand for activities. The models try to estimate the sequence of activities an individual followed in a day, called a *synthetic schedule* or *activity pattern*. Once we know the schedule, to derive the volumes on particular roads in the network is rather straightforward.

The remaining problem to solve is to create a model that estimates the synthetic schedules of individuals. However, the way in which an individual creates his schedule is very complex. It is not feasible to list all the factors that affect individual's planning of the activity schedule; however, the following list contains at least some of them:

- An individual does not plan the whole schedule at one time instant. Scheduling is a continuous process with multiple time horizons.
- There are many constraints that affect the decision making process, such as interactions with the environment, or other individuals in the study area. The schedules have to reflect individuals' needs for participating in activities, the performance of the transportation system, availability of transportation supply, and many other issues.
- It is a very difficult task to measure these constraints. These constraints may vary between individuals and might be purely subjective.
- Two individuals facing the same constraints may, and probably would, develop different schedules.
- The process is not exactly an optimization problem (Simon 1983). People are usually not comparing all possible schedules and picking the best one. They often tend to use one that has worked in the past, even though there could be another schedule that is "more optimal" from an objective point of view.
- There are many factors in the schedule that need to be specified, for example number of activities to be scheduled and their sequencing, the timing, duration, and company of each activity, travel mode to and from this activity and others. The dimensionality of such a problem is very high (see "The fundamental modeling problem" later in this proposal for an example and explanation).

- There are many different aspects of the schedules that must be determined. Most of the models proposed need to assume a hierarchy of causality (nested logit is often used, for example in Wen and Koppelman (2000)). For example, does a person first decide on timing of an activity, and the timing then conditions its duration, or the other way around (Pendyala 2003)? What about activity sequencing, travel mode used and other factors? Previous research has not succeeded in clearly determining this causality (Doherty 2003) even though it is essential for performance of many models.

This listing of a few issues should demonstrate the complexity we are facing. We are dealing with human behavior and decision-making processes. The examples listed above should also bring the impression that a simplification is necessary for any modeling attempt.

A lot of effort has been spent on this problem, and knowledge in the field has developed significantly. Many different models have been proposed; some of them are described in this proposal. There is no single model that considers all of the issues that a real human being considers during her/his activity planning procedure.

This thesis introduces a microsimulation model that generates the synthetic schedules of individuals in a given study area. The proposed algorithm belongs to the field of activity-based approaches to travel demand analysis. It does not aim to follow the human decision making process. More likely it aims to replicate the observed patterns that implicitly include the constraints and the result of the decision making process. By replicating the entirety of a person's activity-travel pattern in a day, a feasible and robust solution that consists of timing and sequencing of activities is provided. The synthetic schedules will be linked to individuals' and household's characteristics (such as income, number of cars, number of children, age, gender, and others).

The principle of the proposed algorithm is briefly described in the following paragraph. More detailed description follows in the second part of this proposal.

All households will be aggregated into groups based on their socio-demographic characteristics. These groups are called *life stages* or *life cycle stages*. Using a clustering method (for example k-means algorithm), a set of *representative activity patterns* (RAPs) will be found for each of these groups. Each household will be assigned to one RAP. However, we do not want all households that belong to the same RAP to have exactly the same schedule. One of the challenges of this approach is to find an algorithm that modifies the “typical” pattern (last step in CBR) to represent variance among schedules. A microsimulation model will be used in order to capture this variance in the data. It will assign each individual in this household to particular activities, using probabilities derived from the observed data.

The main contribution of the proposed approach is in capturing the interactions among household members. For example in a family with a child of school age, one of the parents has to adjust her/his schedule in order to be able to drop the child in the morning to school. Other example can be a joint dinner of both parents. Both of them have to adjust their schedules in order to meet at the same time and at the same restaurant. These examples should demonstrate the importance of such a model. The previous research shows that a household and not an individual is an elementary unit of the decision-making process.

ABSTRACT

ROUTING PROBLEMS WITH SELECTION DECISIONS: ALGORITHMS AND IMPLEMENTATIONS

Hao Tang
The Pennsylvania State University

Dissertation Committee:

Dr. Elise Miller-Hooks (Chair)

Dr. Ageliki Eleftheriadou

Dr. Konstadinos Goulias

Dr. Susan Xu

This dissertation addresses a class of routing problems in deterministic, stochastic or dynamic environments. The problems considered possess a common characteristic that only a select subset of all customers are included in solution tours. For this reason, these problems are referred to as Routing Problems with Selection Decisions (RPSDs). Specifically, as part of this work, problem formulations and solution procedures to the Probabilistic Generalized Traveling Salesperson Problem (PGTSP), Selective Traveling Salesperson Problem with Stochastic Service Times (SSTSP), Selective Vehicle Routing Problem (SVRP) and Selective Vehicle Routing Problem with Time-Dependent Rewards (SVRPTD) are posed.

The importance of vehicle routing-related problems has long been recognized due to the abundance of practical applications. In the past several decades, an enormous number of works have been published to address a variety of routing problems, including the well-known Traveling Salesperson Problem (TSP) and Vehicle Routing Problem (VRP). Most of these published works focus on deterministic routing problems, assuming that all customers must be visited. These works do not consider contexts where only a subset of all customers can be visited. However, in many real-world applications, not all considered customers can be included in solution tours due to practical limitations, e.g. vehicle capacity or tour duration limits. Moreover, the problems may be stochastic and/or dynamic in nature. Solution techniques derived solely from deterministic and static

settings may not adequately address these stochastic and dynamic problems. The main motivation of this dissertation is due to the importance of the applications for the RPSDs and the gap that exists in the literature. Specifically, the primary contributions of this work include: (1) mathematical formulations for the addressed RPSDs; (2) exact algorithms for solving the PGTSP and the SSTSP; (3) heuristics (greedy and metaheuristic) for solving the four considered RPSDs; and (4) implementation of a tabu search heuristic for the SVRPTD on a large real-world service scheduling problem.

The proposed routing problems have numerous applications in a variety of arenas. Through the proposed models and solution techniques, schedules that will result in better service and greater efficiency can be obtained. This will lead to improved customer satisfaction and reduced operational costs.

The first RPSD addressed is the PGTSP. The PGTSP is an extension of the Probabilistic Traveling Salesperson Problem (PTSP) and the Generalized Traveling Salesperson Problem (GTSP). Given a number of customer locations that are partitioned into a set of clusters, the PGTSP seeks the minimum expected length tour on a subset of all customer locations such that the tour traverses each cluster at least once and, in actual operations, those clusters with no realized demand are skipped. Potential applications of the PGTSP include, among others, routing aircraft for overnight delivery, analyzing travel behavior in trip-chaining activities and modeling the probabilistic traveling buyer's problem. Exact and heuristic solution procedures are developed for the PGTSP and related properties are derived. Numerical experiments conducted on randomly generated problem instances show that the exact algorithm based on the integer L-shaped method can solve small- and moderate-size problems to optimality and a greedy insertion heuristic is able to provide competitive approximate solutions with limited computational effort.

The second problem addressed in this dissertation is the SSTSP, where customer service times are known *a priori* only probabilistically. The objective of the SSTSP is to determine an *a priori* maximum profit tour such that the likelihood that the total actual tour duration on a given day exceeds a given threshold is less than a chosen

probability value. Potential applications include service scheduling over a geographic region, the orienteering problem and scheduling a recruiter for recruiting football team members. An exact branch-and-cut algorithm and a construct-and-adjust heuristic are proposed to solve the SSTSP. Numerical experiments are conducted to assess the effectiveness of these solution procedures. Results from these experiments show that the exact algorithm is able to solve small- and moderate-size problems to optimality and the heuristic can obtain near-optimal solutions efficiently.

The third RPSD studied is the SVRP, where, instead of imposing capacity constraints as in the classical VRP, vehicle tours are subject to tour duration (or length) limits. This extends the concepts of the STSP with deterministic service times to multiple tours (i.e. vehicles). Unlike the classical VRP, the SVRP does not require that all customers under consideration be included in solution tours and its goal is to construct a set of tours that maximize total collected rewards received from visiting customers. Applications considered in the literature include home fuel delivery, the team orienteering problem, and a special class of pickup/delivery problems with high volume of requests. A tabu search heuristic is developed to solve the problem. The effectiveness of the proposed tabu search approach is examined on a set of benchmark problems through comparisons of solution quality with other existing heuristic solution techniques for the SVRP. The experiments indicate that the tabu search heuristic proposed in this dissertation outperforms other published heuristics in the literature.

The last RPSD addressed is the SVRPTD, an extension to the static SVRP, where rewards collected by servicing customers are time-dependent. This problem is illustrated through a real-world scheduling application identified by a large international firm. The tabu search heuristic developed for the static SVRP is modified to address this time-dependent SVRP. Numerical experiments conducted on the data sets derived for this considerably large-size real-world application show that the proposed tabu search is able to provide close to optimal solutions for this problem in reasonable computational effort.

A Comparative Study of Weaving Sections in TRANSIMS and Highway Capacity Manual

Srinivas Jillella

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Master of Science
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Civil and Environmental Engineering

Dr. Antoine Hobeika, Chairman

Dr. John Collura

Dr. Hesham Rakha

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A Comparative Study of Weaving Sections in TRANSIMS and Highway Capacity Manual

Srinivas Jillella

Abstract

Weaving is defined as the crossing of two or more traffic streams traveling in the same direction along a significant length of the highway without the aid of traffic control devices. The traditional methods used for the design and operational analysis of a highway is the Highway Capacity Manual (HCM). These traditional methods in the manual use road geometry and traffic volumes as input and provide an estimate of the speed as an output. TRANSIMS is a new computer simulation package in transportation that can be used as an analysis as well as a planning tool. The Microsimulator in TRANSIMS deals with the actual simulation of traffic on roadways. The intent of this research is to evaluate TRANSIMS Microsimulator and compare it with the traditional Highway Capacity Manual in modeling the weaving sections on a freeway and make recommendations. This research will also compare the modeling strategy and provide analysis of the output.

Utilization of Instrument Response of SuperPave™ Mixes at the Virginia Smart Road to Calibrate Laboratory Developed Fatigue Equations

**Walid M. Nassar
The Via Department of Civil and Environmental Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061**

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**Imad L. Al-Qadi, Chair
Gerardo W. Flintsch
Kenneth L. Reifsnider
Antonio A. Trani
John C. Duke**

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Walid M. Nassar

**The Via Department of Civil and Environmental Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA 24060, 2001**

ABSTRACT

In the current mechanistic-empirical (M-E) design procedures for flexible pavements, the primary transfer functions are those that relate (a) maximum tensile strain in the hot-mix asphalt (HMA) surface layer to fatigue cracking and (b) compressive strain at the top of the subgrade layer to rutting at the surface. These functions, called fatigue and rutting equations, are usually derived from statistically based correlations of pavement condition with observed laboratory specimen performance, full-scale road test experiments or by both methods. Hot-mix asphalt fatigue behavior is an important component of a M-E design procedure; unfortunately, most of the existing models do not reflect field fatigue behavior. This is manifested in the fact that HMA fatigue failure is achieved much faster under a laboratory setting than in a field environment. This difference has been typically accounted for by the use of a single shift factor based mainly on engineering experience.

The flexible pavement portion of the Virginia Smart Road includes 12 different flexible pavement designs. Each section is approximately 100m long. The sections are instrumented with pressure cells, strain gages, time-domain reflectometry probes,

thermocouples, and frost probes. The instruments were embedded as layers were built. Laboratory fatigue tests of field cores and field-mixed laboratory-compacted specimens along with measured response from the instrumented pavement sections at the Virginia Smart Road were used to quantify the differences between laboratory and field environments.

Four shift factors were identified to correlate field and lab fatigue behavior: stress-state, material difference, traffic wander, and healing. Field-measured critical strains and strain energy exerted during truck loading were both used to determine the stress state shift factor. Strain measurements of truck loading distribution (wander) were used to determine the wander shift factor. Finally, results from laboratory fatigue tests on cores and laboratory compacted specimens were used to evaluate a shift factor to account for the difference in compaction procedures. While the derived shift factors utilize the measured stresses and strains at the Virginia Smart Road, calculated strains and stresses, based on appropriate pavement and loading modeling, may also be used.