CALIBRATION AND ESTIMATION OF DYNAMIC TRAFFIC ASSIGNMENT PROCEDURES

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Abstract: Under Intelligent Transportation Systems (ITS), real-time or daily operations of traffic management measures depend on long-term planning results, such as origin-destination (OD) trip distribution; however, results from current planning procedure are unable to provide fundamental data for dynamic analysis. In order to capture dynamic traffic characteristics, transportation planning models should play an important role to integrate basic data with real-time traffic management and control. In this research, an estimation framework for dynamic traffic assignment is proposed and field data is applied in estimation and calibration processes. In this framework, results from transportation planning projects in terms of Origin-Destination (OD) trips, are considered and extended to the dynamic models. DYNASMART, a simulation-assignment model, is applied to generate time-dependent flows. The results show high agreement between actual flows from vehicle detectors and simulated flows from DYNASMART.

Key Words: Dynamic Traffic Assignment, Time-Dependent Origin-Destination (OD), DYNASMART

1. INTRODUCTION

Three principal dimensions are of interest in the dynamic analysis of traffic flow patterns in urban networks: (1) time-dependent flow patterns within a given day; (2) day-to-day dynamics; and (3) real-time dynamics (Mahmassani, 1990). Dynamic models have been developed to utilize ITS technologies; however, results from the dynamic models still need to be evaluated and calibrated through empirical data.

The last step in sequential aggregate transportation planning procedure is the assignment of origin-destination flows to actual routes. Traffic assignment techniques include: static traffic assignment, stochastic assignment, and dynamic traffic assignment. Static and stochastic assignment procedures assume that each vehicle is simultaneously located on every link on its chosen paths. However, each vehicle should travel through time as well as space from its origin to its destination. Although the static assignment assumption is accepted for many regional transportation planning applications, the static representation of network performance is not sufficiently accurate for many applications.

Transportation planning procedures, due to the static essence, could only be applied in long-term transportation projects. Under ITS, real-time or daily operations of traffic
measures depend on long-term planning results; however, current planning procedure could not provide fundamental functions for dynamic analysis. In order to capture dynamic traffic characteristics, transportation planning models should play an important role to integrate basic data with real-time traffic management and control (FHWA, 2001, 2002).

This research aims at developing an estimation framework for dynamic transportation planning. In the framework, time-dependent OD trips are estimated based on OD trips obtained from transportation planning projects, and the data of time-dependent OD trips is used in dynamic simulation-assignment models in order to generate time-dependent flow distribution in a traffic network. The resulting flow distributions consider possible temporal as well as spatial variations of OD trips in a network, thus could be used to develop traffic management strategies. The overall system is illustrated through numerical experiments based on the northern part of freeway network in Taiwan, and dynamic variations in traffic flow patterns are observed and compared with data collected from vehicle detectors (VD).

Next section presents a brief review of related problems and research methodologies. The proposed overall framework is discussed in Section 3, and two associated algorithmic procedures are explored in Section 4. Numerical experiments and results from the northern part of freeway network in Taiwan, used to illustrate important aspects involved in this procedure, are discussed in Section 5, followed by a brief summary.

2. LITERATURE REVIEW

2.1 Transportation Planning
Transportation planning has reflected the policy concerns and issues of the times in which it was occurring. Highway construction and expansion has been the important issue since 1950 around the world. Recent transportation laws, regulations, and policies have encouraged the development of a multimodal transportation planning process. Multimodal transportation planning could be defined as (Meyer and Miller, 2001):” The process of defining problems, identifying alternatives, evaluating potential solutions and selecting preferred actions that meet community goals in a manner that includes all feasible transportation modes.” According to Meyer and Miller (2001), Three major components, including transportation system supply, transportation demand, and land use, are concerned in the transportation system.

The Urban Transportation Planning System (UTPS) is used to predict the number of trips made within an urban area by type (work, network, etc.); time of day (peak period, daily, etc.); zonal origin-destination (OD) pair; the mode of travel used to make these trips; and the routes taken through the transportation network by these trips. The final product of UTPS is a predicted set of modal flows on links in a network. UTPS consists of four major stages and is often referred to as the four-stage or four step model; (1) trip generation; (2) trip distribution; (3) modal split; (4) trip assignment. The four stages of UTPS represent a pragmatic approach to reducing the extremely complex phenomenon of travel behavior into analytically manageable components that can be dealt with using relatively simple techniques and reasonable amount of data.

2.2 Dynamic Network Assignment
Traffic assignment aims at studying network performance by finding the link flows for given demands. Static network assignment has been studied in extensive detail over the last two
decades (Sheffi, 1985), and has been applied to study or evaluate how network flows are distributed spatially in a traffic network. Without capturing the dynamic nature of transportation systems, the static assignment models cannot adequately address congestion periods.

ITS has stimulated the development of dynamic traffic assignment in which a central controller with partial or complete information on time-dependent OD trips desires aims at achieving certain systemwide objectives by providing real-time routing information and/or route guidance instructions (Ben-Akiva et al., 2001; Boyce et al., 2001; Mahmassani, 2001).

All mathematical programming-based formulations in essence do not appropriately model the traffic flow characteristics; as a result, heuristic procedures combined with traffic simulation have been proposed. A heuristic iterative procedure, for solving dynamic traffic assignment problems was proposed by Mahmassani et al. (1994). In this procedure, a traffic simulation model is used to capture the traffic interactions in networks and thereby evaluate the performance of the system under a given assignment. The use of a traffic simulation model in the evaluation of the system optimal objective function circumvents the principal difficulties in dynamic traffic assignment problems by obviating link performance functions and link-exit functions, and implicitly considering the first-in, first-out properties.

2.3 DYNASMART
DYNASMART (DYnamic Network Assignment-Simulation Model for Advanced Road Telematics) is developed to describe the evolution of time-dependent flows based on individual tripmakers' decisions of departure time and route as well as their en-route switching decisions (Mahmassani et al, 2002). DYNASMART uses an assignment-simulation modeling approach to assign time-varying traffic demands, model the corresponding traffic patterns, and evaluate network performance. In its present form, DYNASMART is primarily a descriptive analysis tool for the evaluation of information supply strategies, traffic control measures, and routing strategies at the network level. The model is designed to meet functional requirements for ATMS/ATIS applications, including sensitivity to a wide range of traffic control measures for both intersections and freeways, capability to model traffic disruptions due to incidents and other occurrences, and representation of several user classes corresponding to different vehicle performance characteristics, different information availability status and different behavioral rules.

3. CONCEPTUAL FRAMEWORK FOR DYNAMIC TRANSPORTATION PLANNING

Three principal dimensions are of interest in the dynamic analysis of commuter decisions and associated flow patterns in urban networks: (1) time-dependent flow patterns within a given day; (2) day-to-day dynamics of commuter decisions; and (3) real-time dynamics (Mahmassani, 1990). However, time-dependent and day-to-day flow patterns might impact how tripmakers choose modes as well as locations. In this research, results from planning procedures are basic input to generate time-dependent flow patterns and aggregate results from time-dependent traffic assignment can thus feedback to planning procedures. In order to explore dynamic transportation planning procedures, an overall conceptual framework is proposed and associated modules are described and discussed. Two major issues, time-dependent OD adjustment process and Link-by-link time-dependent flow comparison process, are further discussed in the next section.
The unified dynamic transportation planning framework, as shown in Figure 1, integrates the four-step planning procedures, dynamic traffic assignment from ITS technologies, Geographic Information Systems, and traffic information. These modules are constructed based on GIS-T, thus data could be efficiently managed. Several important components are identified and interrelationships among these components are discussed in the following sections.

**Transportation Planning Module**

Three major stages from transportation planning procedures adopted in the procedure are trip generation, trip distribution, modal split. First, land use and economic activities are investigated for traffic zones within the studying area, then flow counts from cordon line are used to modify OD trip tables. The generated OD trips are assigned to traffic networks according modal split and assignment techniques. The planning module provides basic input data for dynamic traffic assignment module, such as OD trips. Several advantages through the planning module are summarized as follows:

1. The planning procedure usually includes extensive surveys for traffic systems and OD trips, thus could provide fundamental input for both dynamic assignment module and real-time control module.

2. The planning module could receive information and data from the other two modules, and these information and data are further feedback to different stages. For example, flow counts could be used in adjusting OD trip generation and distribution, and travel impedance could be used in both modal split and assignment.

![Figure 1 Conceptual Framework for Dynamic Transportation Planning](image_url)
Dynamic Traffic Assignment Module
This module aims at providing temporal and spatial analysis of traffic flows in a traffic network. Major components within this module are dynamic OD estimation, traffic simulation, traffic control strategies, and route generation and assignment. Static OD trip data taken from Transportation Planning Module is further analyzed according to time, and time-dependent OD trip data is generated through OD adjustment Process. With the time-dependent OD matrices, person trips are converted to vehicle trips, such as vehicles, buses, and motorcycles. These vehicles are then loaded in sequence onto the traffic network, and vehicle movements are simulated in a realistic traffic environment. Flow information and travel time statistics are gathered and disseminated to the real-time control module as well as the planning module. Day-to-day flow variations are gathered as part of historical travel information, and time-dependent OD trips could thus be refined and adjusted.

Real-Time Control Module
This module aims at providing real-time traffic flow analysis based on real-time collected data, thus possible route guidance and real-time control strategies could be designed accordingly. The real-time control module generates real-time travel information and real-time traffic control strategies according real-time data and input from the other two modules. Basic functions of the real-time control module include:

1. Based on all information, such as historical information from the planning module, simulation information from the assignment module, and real-time information from detectors, the real-time control module generates predicted information for route guidance.
2. Normative and/or descriptive routes are generated based on the assumption on tripmaker route choice behavior.
3. Real-time control strategies are generated based on shorter-term OD prediction and current flow situations.

Since the real-time control module estimates and predicts possible short-term variations based on information provided by real-time detections, the planning module and the assignment module, possible accuracy could be achieved in a short term horizon. Thus, the tripmaker could receive information, and makes individual decisions on route switching and/or mode choices.

Geography Information Systems For Transportation (GIS-T)
Through the operation of these three modules, OD trips and flow information could be consistently gathered in three time horizons, namely, long-time, short-term, and real-time. However, every processes involve tremendous calculations and large amount data are needed and used in different calculation steps. In order to manage these data intelligently, GIS-T have been widely used and employed in transportation planning process, the proposed framework constructed numerical data, digitized maps, transportation data, such as traffic zone, in the TransCAD.

Interrelationship between the planning Module and the assignment module
Outputs from the planning procedure include time-dependent OD trips by mode, and thus could be assigned into a traffic network. However, time-dependent flow information needs to be aggregated for trip distribution process and modal split process. Convergence characteristics might be highly correlated with the method of aggregation.
4. TIME-DEPENDENT OD ESTIMATION AND SIMULATION PROCESSES

4.1 Time-Dependent OD Adjustment Process
Traditionally, a daily OD demand trip table is generated for every mode in the transportation planning process, and this OD is static in essence. This research focuses on time-dependent simulation-assignment process, thus accurate time-dependent OD matrices are required to generate reliable time-dependent flows. A heuristic approach is proposed to generate time-dependent OD demand data, and the heuristic approach utilizes temporal flow data from toll stations. The heuristic approach is illustrated in Figure 2. Simulated flow from DYNASMART is compared with actual flows from toll stations, and the error is used to generate adjustment factors. The algorithmic steps are summarized as follows:

**Step 1. Examine Total Number of Vehicles**
Examine the total simulated vehicles according to exogenous information, such as other related projects and census data. If the total number of vehicles $OD^i$, the total number of trips for a particular day $i$, is not correct, then adjust the demand accordingly. The total OD trips are controlled within this range.

**Step 2. Examine flow distributions**
From prior experience, major routes taken by most of the vehicles are highways; therefore, initial routes for most of the assigned vehicles should include freeway links. The best paths generated for each time interval are examined and the results of flow distribution are observed.

**Step 3. Determine Time-Dependent OD Pattern**
In this study, time-dependent OD demand matrices are generated through a static 24-hour OD demands, $OD^i_t$ is defined as the demand trip for time $t$ (the time interval is assumed to be one hour) on a given day $i$. The generated matrices are used to simulate time-dependent flow distribution through DYNASMART. In this study, time-of-day factors, 7%, 8%, 9%, and 5%, are used for the considered time period, 6:00-10:00AM, which represents a morning peak period. The simulated flows are compared with actual, time-dependent link volumes of toll stations for a 2-hour period, 7:00 to 9:00 AM. The time-dependent flows are aggregated on the basis of 5 minutes; therefore, there are 24 sample points for each link.

**Step 4. OD Adjustment Process**
According to geometric location of toll stations, influence areas are identified for OD adjustment. The differences between simulated and actual flows are used to estimate adjustment factors, and the factor is applied for the specific influence zone. The adjustment factor for $j$ iteration, $\alpha_j$, is defined as follows:

$$\alpha_j = \frac{F_a}{F_s}$$

Where $F_a$ represents actual flows obtained from toll stations, and $F_s$ represents simulated flows from DYNASMART. The adjustment process is applied to each toll station sequentially, and the factors $\alpha_j$ should converge to 1.0 in the final state.

**Step 5. Stop Rule**
If the adjustment factors $\alpha_j$ are equal to 1.0, then stop. Otherwise, go to step 4, and repeat
the process.

Figure 2 Time-Dependent OD Adjustment Process

4.2 Link-by-Link Comparison of Time-dependent Flows
Based on the previous discussion, the flowchart of numerical experiments is illustrated in Figure 3. Historical OD is the major input data, and DYNSMART is applied to perform dynamic traffic assignment procedure. The simulation results are extracted for a time period of 120 minutes (60-180 minutes in the simulation run), and flow data is aggregated for each 5 minute interval. The simulated flow is compared with the actual flow from vehicle detectors. The percentage relative error is used in real-time OD estimation process. However, real-time OD estimation process is discussed in a separate paper.
5. NUMERICAL EXPERIMENTS AND RESULT ANALYSIS

In this section, numerical experiments, including data collection and results, are discussed. Several results are analyzed, including OD adjustment process, actual and simulated flow comparisons for toll stations, and actual and simulated flow comparisons for vehicle detectors. Percentage relative error (PRE) is used to express error between actual and simulated flows. The percentage relative error is defined as the absolute error by multiplying by 100%.

5.1 Data Collection
The data collected for the numerical experiments include 4 parts: network characteristics, static OD demand trips, actual flow data from toll stations, and actual flow data from vehicle detectors (VD).

5.1.1. Network Configuration
The study area covers the northern part of freeway network in Taiwan, there are 2 north-south bound freeways (official name: Freeway I and Freeway III) and 2 east-west bound freeways. Since only a limited number of vehicle detector are installed on east-west bound freeways, freeway 1 and freeway 2 are used to represent two north-south bound freeways. The network, as depicted in Figure 4, includes 810 links and 692 nodes, and 36 traffic zones.
5.1.2. OD Demand Data
The OD demand in the experiment is based on the project, titled of “National Intercity Travel Demand Analysis.”, and new traffic zones are synthesized through original zones. There are totally 36 traffic zones in this study, and 3 external zones are added to represent traffic outside of the study area.

5.1.3. Flow data from toll stations
In this network, there are four toll stations, as illustrated in Figure 3. In order to simplify the discussion, toll stations are renamed as in Table 1. The data is collected from June 1, 2005 to July 31, 2006 for a period of one whole year. Two typical 24-hour flow distributions are illustrated in Figure 5, which show temporal flow distributions for the toll station A. In general, there are two peaks in the distribution. The morning peak appears from 6:00-9:00 AM, and the afternoon peak appears from 5:00-8:00 PM.

5.1.4. Flow Data from Vehicle Detectors
In the study area, vehicle detectors are installed to measure flows on freeways. In average, there is a detector for every 2 kilometer section. The data is aggregated for every 5 minutes, as illustrated in Figure 6.

<table>
<thead>
<tr>
<th>Name</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taishan Toll Station</td>
<td>A</td>
</tr>
<tr>
<td>Sulin Toll Station</td>
<td>B</td>
</tr>
<tr>
<td>Cidu Toll Station</td>
<td>C</td>
</tr>
<tr>
<td>Sijih Toll Station</td>
<td>D</td>
</tr>
</tbody>
</table>
5.2 Result Analysis: OD adjustment Process

5.2.1 The OD adjustment Process

The adjustment factors are summarized in Table 2. There are 6 toll stations, numbered A-North, A-South, A-North, A-South, A-North, and A-North. Time original time-dependent OD matrices are adjusted according to these factors till the equilibrium state is reached.

<table>
<thead>
<tr>
<th>Toll Station</th>
<th>Iteration</th>
<th>A-North</th>
<th>A-South</th>
<th>B-North</th>
<th>B-South</th>
<th>C-North</th>
<th>D-North</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.</td>
<td>1.5</td>
<td>2.0</td>
<td>0.8</td>
<td>0.9</td>
<td>1.1</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>2.</td>
<td>1.6</td>
<td>1.5</td>
<td>0.8</td>
<td>1.0</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>3.</td>
<td>1.0</td>
<td>1.2</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>4.</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Table 3 Comparisons of Actual and Simulated Flow Volume

<table>
<thead>
<tr>
<th>Toll Station</th>
<th>A-North</th>
<th>A-South</th>
<th>B-North</th>
<th>B-South</th>
<th>C-North</th>
<th>D-North</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Flow Volume</td>
<td>16,804</td>
<td>19,033</td>
<td>8,782</td>
<td>12,242</td>
<td>2,269</td>
<td>15,494</td>
</tr>
<tr>
<td>Before</td>
<td>2-HR Simulated Flow Volume</td>
<td>12,137</td>
<td>10,294</td>
<td>10,297</td>
<td>12,058</td>
<td>2,037</td>
</tr>
<tr>
<td>PRE (%)</td>
<td>27.8%</td>
<td>45.9%</td>
<td>17.3%</td>
<td>1.5%</td>
<td>10.2%</td>
<td>68.72%</td>
</tr>
<tr>
<td>After</td>
<td>2-HR Simulated Flow Volume</td>
<td>16,146</td>
<td>17,198</td>
<td>9,987</td>
<td>14,015</td>
<td>1,969</td>
</tr>
<tr>
<td>PRE (%)</td>
<td>3.9%</td>
<td>9.6%</td>
<td>13.7%</td>
<td>14.5%</td>
<td>13.2%</td>
<td>9.8%</td>
</tr>
</tbody>
</table>

5.2.2 Comparison of Flow Volumes
The comparisons of actual and simulated flow volume are summarized in Table 3. The actual total volumes for 2-hour periods for each toll stations are listed in the second row. After the OD adjustment, the values of PRE are ranged from 4% to 15%, and the results indicate satisfactory agreement for total volume comparison. The improved is achieved mainly for toll stations A-North, A-South, and D-North.

5.2.3 Temporal flow Comparison
Temporal flow distributions before and after OD adjustment are illustrated in Figures 7 and 8 for toll stations, A-North and A-South. The illustrations show the difference of simulated flows and actual flows before and after the OD adjustment process. The gap before the adjustment process is much larger than the gap after the process. It indicates the possible efficiency of the adjustment process. Although there are some discrepancies in this comparison, the differences between simulated and actual flows tend to reduce. The high agreement between these two flow patterns show possible estimation and prediction capabilities for both freeways.

Figure 7 Temporal Flow Distributions Before and After OD Adjustment for A-North Toll Station

Figure 8 Temporal Flow Distributions Before and After OD Adjustment for A-South Toll Station
5.3 Result Analysis: Results for VD Comparison

As illustrated in Figure 9, aggregate flow distributions within 2-hour period are examined spatially first. The detectors from north to south are listed in the horizontal axis, and link volume is plotted in the vertical axis. The results of aggregate flow on freeway 1 show some variations; especially the pattern from north to south on freeway 1.

Time-dependent flow distributions for actual and simulated flows on vehicle detectors are compared and the values of PRE (percentage relative error) are calculated. The number of detectors considered in the comparisons is about 80. Results analysis focuses on aggregate behavior of time-dependent flow distributions. The value of PE indicates accuracy of the comparisons. As shown in Figures 10 and 11, the horizontal axis represents the location of detectors, and the vertical axis represents PRE.
1. Freeway 1

In Figure 10, most of the PE values are within a range of 75% for north-bound links on Freeway 1. However, there are few links which have higher PE value range from 100% to 200%. These links are located in the north part of freeways. Possible reasons are (1) these detectors are near the boundary of the study area, thus OD trips are difficult to estimate; (2) traffic zones might not reflect possible trips coming and going within this area. In Figure 10, most of the PE values are within a range of 50% for north-bound links on Freeway 1. Only one link has a very high error, and this might be a malfunction of the detector.

2. Freeway 2

In Figure 11, most of the PE values are within a range of 25% for north-bound links on Freeway 1. Only one link has a higher error, and this link is also near the boundary of the study area. In Figure 11, most of the PE values are within a range of 25% for south-bound links on Freeway 1. The results show high agreement between actual and simulated flows.

3. Overall Comparison

The overall performance of the comparison is measured through the distribution of error percentage, as illustrated in Figure 12, in which the horizontal axis represents the range of percentage of error, and the vertical axis represents number of detectors. In general, there are 40 sets of VD which have error less than 20%, and there are 18 sets of VD have error within 20-40%. The percent of VD within 0-40% are about 70%. The results show high agreement between actual and simulated flows and the results also indicates the reasonableness and appropriateness of the time-dependent OD adjustment process.

6. CONCLUSIONS

In this paper, a heuristic procedure for time-dependent OD generation is proposed, and several important issues are raised and discussed. Numerical experiments based on real data of the highway are conducted to illustrate the interaction between the planning procedure and the assignment procedure. Dynamic scenarios of dynamic traffic management can be simulated and modeled in the new model. Thus, ITS related projects could be investigated and reviewed through the dynamic transportation planning procedures and possible benefits can also be assessed. The numerical results indicate that dynamic transportation planning procedure could provide detailed flow variations within the studying horizon; thus, real-time control and route guidance can take full advantages of this information. Possible development in the future includes route generation and improvement process and time-dependent issue consideration.
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REFERENCES


