Using traffic prediction models for providing predictive traveller information

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Abstract: As a subsystem of an Intelligent Transportation System (ITS), an Advanced Traveller Information System (ATIS) disseminates real-time traffic information to travellers. To help travellers better make their route choice decisions, there is a strong need to predict traffic congestion and disseminate the predicted congestion information to travellers. This paper offers some insights and predictions on how ATIS information provision is becoming more pervasive due to recent advances in telecommunication systems. The paper also discusses how ATIS systems will likely evolve based on the experiences of Information Service Providers (ISP) and ATIS modelling specialists. Then, it reviews four types of prediction models: 1) simulation models; 2) dynamic traffic assignment (DTA) models; 3) statistical models; and 4) heuristic models. The functional requirements and capabilities of the four types of prediction models are discussed and summarized. Furthermore, a comprehensive prediction procedure is presented, which combines the four types of prediction models.

Keywords: Intelligent Transportation System; Advanced Traveller Information System; traveller information provision; predictive traffic information.

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1 Introduction

Intelligent Transportation Systems (ITS) are being developed to use computer, information technologies, and telecommunications to improve the efficiency, productivity and safety of the existing transportation system. In addition to North America, many European and Asia-Pacific countries have also invested heavily in the development of ITS systems. In recent years, various ITS operational demonstration projects have been deployed worldwide in Chicago, Paris, Tokyo, and numerous other locations. As ITS subsystems, an Advanced Traveller Information System (ATIS) disseminates real-time traffic information to travellers, and an Advanced Transportation Management System (ATMS) optimally manages traffic flow and reduces congestion in a metropolitan area.

For an ATIS system, various traffic surveillance systems, such as loop detectors for sensing vehicles, video cameras, and probe vehicles, are used to collect real-time traffic information on a highway network. When the real-time traffic data are collected from field devices and transmitted back to the Traffic Information Centre (TIC) via dedicated telecommunication systems, these data are processed into various types of databases at the TIC. Then, travellers can access this processed real-time traffic information via telephone, fax, pager, radio, TV, and internet. For example, drivers could receive repetitive AM radio broadcasts on traffic conditions of key routes during their commute. Some users could also browse the internet to check current traffic conditions via real-time internet congestion maps.

The success of ATIS and ATMS depends on the availability and dissemination of accurate and timely estimates and predictions of traffic conditions. Currently, ATIS depends almost exclusively on static and current information. The next generation of ATIS systems will exploit the potential of traffic prediction models to develop value-added traveller information. This is possible in large part due to improvements in telecommunication systems. Traveller information systems are gradually becoming one of the cornerstones of the ITS industry. While it is difficult to predict when the traveller information market will take off, public agencies and private companies are investing significant resources to develop and operate various ATIS systems. As identified in ITS user services, the predictive traveller information is indispensable, partly due to the lack of sufficient sensoring devices to collect enough real-time information to cover major motorways and arterial streets.

Although predictive traveller information is widely recognized as important, there exists a big gap between ATIS practitioners and researchers in terms of how predictive traveller information should be obtained and disseminated. To bridge this gap, the objective of this paper is to identify the functional requirements and capabilities of prediction models with some near-term and mid-term perspectives for providing predictive traveller information in ATIS practice. This paper will also offer some insights and predictions on how ATIS information provision, especially the predictive traffic information provision, will likely evolve based on the experiences of Information Service Providers (ISP) and ATIS modelling specialists.

The current practices of traveller information provision are first reviewed and the perspective of near-term and mid-term practices of traveller information provision is offered in Section 2. Then, traffic prediction models are reviewed in Section 3. To develop operational prediction models for a traveller information system, the functional requirements, capabilities, and data needs must be defined. In this paper, these functional requirements and capabilities will be summarized in Section 4. A comparison of functional requirements and capabilities of these prediction models will be provided as well. In this comparison, a specific analysis will be made in terms of the advantages and disadvantages for each type of model. Furthermore, the roles of all prediction models will be discussed. Consequently, how the four types of prediction models can be integrated in an operational traffic prediction system will be investigated in Section 5. Finally, some concluding remarks are presented in Section 6.

2 Current and expected practices of traveller information provision

Currently, traveller information provision is based on either static/historical information or current information. Almost no *predictive* traveller information is offered by either public transportation agencies or Information Service Providers (ISP). Table 1 presents the types of multi-modal traveller information, which are currently available and expected to be available in the near future.

As outlined in the ITS System Architecture [1], ATIS systems will evolve from real-time traveller information dissemination to real-time route guidance and route choice coordination in the coming decades. Although the ultimate goal is clearly identified, it is unknown how the current prototype ATIS systems will evolve into mature systems. Many technological and economic factors will affect this evolutionary process. Ultimately, traveller needs will decide this evolutionary path. With some of the ATIS successes and failures in mind and after reviewing the major ATIS/ATMS research efforts, some objective predictions are made in Table 1 regarding when various types of highway information and multi-modal traveller information could be made available for major US cities. These tables are not intended to provide guidelines for ATIS practitioners. But they are presented here in order to present some perspectives and opinions offered by some ISP practitioners and ATIS researchers at recent ATIS workshops.

Table 1 Types of currently available multi-modal information

Facility Classification	*Information Type*			
Highway	Static	Historical	Real-Time	Predictive
Motorway	*	*	*	**
Toll Road	*	*	*	**
Major Arterial	*	***	***	**
Minor Arterial	*			***
Local Street	*			***
Others				
Bus	*	**	***	**
Subway	*	**	**	**
Other Rapid Transit	*	**	**	**
Ride Sharing	*	***	***	
Railway	*	**	**	**
Transit Terminal	*	***	***	
Airline	*	***	*	*
Airline Terminal	**	***	***	

* Information Currently Available
** Information Available Near-Term (2–5 Years)
*** Information Available Mid-Term (5–10 Years)

In a multi-modal traveller information system, providing transit information is much simpler than providing highway information. Furthermore, other modes, such as airlines, would be much easier to provide various static, historical, real-time, and predictive information than for highways, because they use fewer routes and have better information systems than highways. Therefore, in the following discussion, the major focus on predictive traveller information will be put on highways instead of other modes.

3 Review of traffic prediction models

The traffic prediction models for a Traffic Information System will mainly provide predictive information on link travel time and route travel time as well as link/route flows. These models use a network in which links represent streets, and nodes represent intersections. To achieve on-line real-time operations, these models must be easily and quickly solvable and accurate. Furthermore, it is desirable that the output or outbound forecast information on link/route travel times would have a prediction probability of accuracy, similar to weather forecasts. To serve a traveller information system, there are basically four types of prediction models:

1 simulation models

2 Dynamic Traffic Assignment (DTA) models

3 statistical models

4 heuristic models

Among these models, the DTA models and statistical models are the most promising for providing short-term travel time prediction and forecasting. These models will be reviewed in the following.

3.1 Simulation models

Simulation models typically represent each vehicle as an entity and use (pseudo) random numbers to predict various factors. Examples include desired speed, red/yellow traffic light signals, and gap acceptance, which is the acceptable time interval between oncoming successive vehicles before crossing the street. Rigorously speaking, simulation models cannot be used for traffic *flow* prediction purposes since they require the input of traffic flow values for the simulation time period and lack the dynamic route choice behaviour considerations. However, simulation models provide a method to estimate travel *times* once traffic flow volumes have been predicted by other means. In other words, simulation provides an alternative to field calibration of the relationship among flow, occupancy, and travel time.

While it is possible to envision a case where a simulation model could be implemented in real time (i.e., receiving flow predictions, simulating the network, and producing travel time predictions), none of today's candidate models such as TRAF-NETSIM [2] or SATURN [3] are suitable for real-time implementation. In other words, there is a need for refinement of existing models for real-time implementation. Furthermore, changes in the structure of the source code and modelling philosophy must be considered to render such models useful for on-line applications.

Occasionally, simulation models could be used for prediction purposes for very small motorway corridors under stringent conditions. However, this would also require refinement of existing simulation models. The simulated predictions are expectations of travel times. Simulation models can account for the control environment in which trips take place, including traffic signals, stop signs, lane channelization, and the like. These features provide some advantages for simulation models to play a role in prediction problems for motorway corridors with few or no route choice options and origin-destination (OD) requirements. It is noted that simulation models with route choice or assignment capabilities are classified as simulation DTA models.

3.2 Dynamic Traffic Assignment (DTA) models

With the support of the US Federal Highway Administration and the management of Oak Ridge National Laboratory, the development of a real time dynamic traffic assignment (DTA) system is currently under way. For a DTA model, the fundamental route choice behaviour of a traveller is based on the criterion that each traveller uses the route that minimizes his/her actual travel time when departing from the origin to his/her destination. This route choice criterion is termed the ideal dynamic user-optimal (DUO) and could be stated more specifically by the following route choice conditions:

if route flow at time t > 0, route travel time at time t = minimum;

if route flow at time t = 0, route travel time at time t ≥ minimum.

In other words, in an ideal DUO state, each traveller uses a minimum travel time route at each time instant.

In a basic DTA problem, it is generally assumed that the time-dependent origin-destination departure rates are known *a priori*. In other words, the numbers of travellers departing in each time period are given and we must determine which routes will be chosen by these travellers. One important instance of the DUO route choice problem is to determine the dynamic trajectories of link states and inflows and exit flows at each instant of time resulting from drivers using minimal-time routes, given the network, the link travel time functions (which specify travel times as functions of traffic flows) and the time-dependent origin-destination (O-D) departure rate requirements. Other types of DTA problems are generalizations based on different applications and purposes. For each of the applications, a DTA model may have a different set of data needs and computational requirements. For example, DTA models for planning/evaluation purposes can have long computer run-times and more specific data inputs. However, for real-time prediction, computer run-times and data inputs are under more stringent requirements.

There are in general two different approaches for developing DTA models: simulation-based or analytic-based, depending on the formulation approach, solution property and modelling detail. Many of the existing DTA models belong to the first category [4,5]. More or less, each of the simulation DTA models assumes that vehicles are assigned to their individually determined time-dependent minimal travel time routes. Some simulation models use more general assumptions, which are based on time-dependent minimal travel cost, or marginal cost route searching and assignment. The developers of simulation DTA models contend that their approaches approximate the dynamic user-optimal (DUO) route flows and route travel times. However, there is no guarantee that simulation DTA models will actually arrive at the optimal solution with DUO properties, or even at a solution with well-understood properties. For example, the final solution often changes by simply changing the random seed numbers associated with the simulation. Since traffic management or control always assumes some sort of objective, such as minimizing total system delay, the lack of well-defined solution properties of simulation DTA models is a major modelling deficiency.

The second approach is analytic-based dynamic traffic assignment models. Usually, these models are formulated as optimization problems or variational inequalities [6]. The variational inequalities can be converted into optimization problems via relaxation and are solved by using the convex combination method [7]. Currently, the size of solvable networks on a regular PC is approximately 500 links, 500 O-D pairs, and 120 time intervals. Contrary to simulation-based DTA models, solutions of analytical DTA models have well-defined and understood properties. This is a very important point because it is generally believed that DUO route flows and route travel times are fundamental to the prediction and control of traffic management systems, especially for dynamic route guidance and traffic signal control purposes. In contrast to their superior solution properties, one major drawback of analytical DTA models lies in their simplification of some complex traffic representations.

In several sophisticated simulation and analytical DTA systems, travellers are stratified into several classes, depending on their route choice criteria. For instance, travellers can be stratified into three classes as follows:

(i) travellers who either do not have real-time traffic information and hence continue their intended routes, or refuse to change their routing plans

(ii) travellers who determine their routes according to what is perceived to be the lowest travel time when they depart

(iii) travellers who have access to real-time traffic information, and are able to evaluate route choice attributes identically and without error.

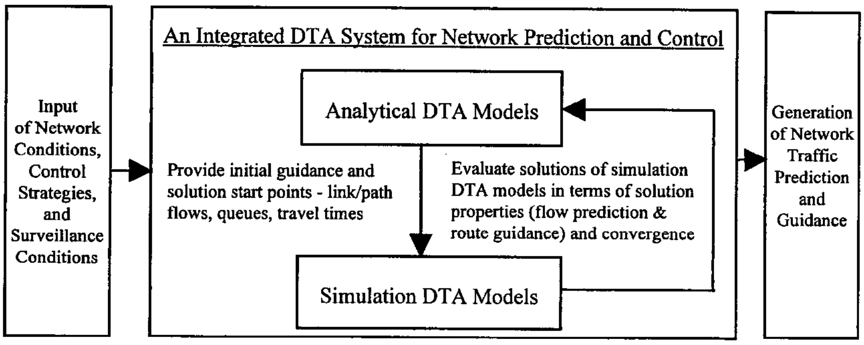
The details of this travellers' classification can be referred to in Ran and Boyce [6] and in Peeta and Mahmassani [8].

While it is infeasible to develop a super model to include all the advantages of both analytical DTA and simulation DTA models and avoid the disadvantages of both models, it is reasonable to develop both types of models in parallel and develop an interface to ensure that the advantages of both types of models are preserved and utilized in an integrated DTA system. In the following, some recommendations for future studies will be presented to implement such an integration. At this point in time, it is important that both approaches should be given equal opportunity for further development. Given the brisk pace of the development of faster computers and telecommunication systems, and the possibility of building better solution algorithms, there is reason to be optimistic that the integrated analytical/simulation DTA system will become a standard tool for providing predictive traffic information in a traveller information system in a few years.

It is also important that the roles of both analytical and simulation DTA models in an integrated operational DTA system are analysed, and an integrated system of both analytical and simulation DTA models is developed. To serve the need of developing an operational DTA system, it is desirable to ensure that the current simulation DTA models have valid solution properties. In other words, it is necessary to guarantee that the solution process of the simulation DTA models will lead to the desired optimal DTA solution in a reasonably fast speed. An integrated approach should be designed to ensure such a solution process. Furthermore, the analytical DTA models could be further refined to serve the needs of evaluating the simulation DTA models.

As shown in Figure 1, in an integrated DTA system, analytical DTA models could be used as a benchmark evaluation tool for simulation DTA models. For example, analytical DTA models could function as a target for dynamic route guidance. An analytical DTA model could provide a solution of dynamic routing based on dynamic user-optimality. The dynamic O-D matrices are used as input for the analytical DTA model. After an analytical DTA model solves for DUO link flows and travel times, it generates routes and corresponding route flows for each O-D pair. The generated routes and route flow information are used as binding criteria for the simulation DTA model. The simulation DTA model then implements detailed route and link flow assignment and generates a new set of route flows and link flows. After the simulation DTA model finishes its iterations, the synchronization and consistency check module compares the routes and route flows from both the analytical DTA model and the simulation DTA model. If there is a large discrepancy, the simulation DTA model needs to be executed again and a new loop needs to be completed. If the discrepancy is acceptable, then output from the simulation DTA model is used as the network traffic prediction and the routing plan for dynamic route guidance.

Figure 1 Integration of analytical DTA models and simulation DTA models



3.3 Statistical models

The statistical models use information on flow conditions in the immediate past to estimate future values of travel time and flow. Statistical models predict traffic flow characteristics by identifying regularities in traffic flows and traffic flow patterns over time. Statistical models may be based on information from a single link or from multiple links. The single link models predict flow on a link from previous flow data on that link. Multiple link models predict flow on a link from flow data on that link and neighbouring links. When link flow is determined, the link travel time can be calculated by using a link travel time function.

As a simple statistical model, the historic profile approach is based on the assumption that an historic profile can be developed for volume or travel time for each link, which represents the average traffic characteristics at each time period over days which have a similar profile. An important component of the historic approach is the classification of days into day types with similar profiles.

A major problem with single-link and multiple-link statistical models is that the predictions generated by these methods tend to ignore the development of any trends during prediction. Consequently, the models may not be useful in situations where there is a trend in the volume profile over an extended period of time, such as when upstream flow increases in the presence of a downstream incident.

3.3.1 ADVANCE model

The ADVANCE Project [9,10] has developed a very comprehensive statistical travel time prediction model. In the ADVANCE statistical model, expected travel time over a given time interval is viewed as a sum of three components: one component that can be estimated long in advance, based on day-type, time of day, etc.; a second component that can be added to the first component and can be forecast based on quantities known just before the forecast is made; and a third component that needs to be treated as randomly varying. The most dominant part of this last component is due to traffic signal cycles. An unbiased estimate of the first component is called a static estimate, and an estimate of the sum of the first two components is called a dynamic estimate. An estimate of the first component may be used as a default estimate when the second component is not available.

An on-line travel time prediction procedure has been developed in the ADVANCE model, which is used for various scenarios, including road closures, presence of incidents, and absence of road closures and incidents.

3.4 Heuristic models

The heuristic models are similar to the statistical models except that heuristical rules are used for the prediction of flow variables instead of formal statistical models. For example, Hoffmann and Janko [11] used the historical profile as the basis for a heuristic short-term prediction procedure. Dougherty *et al*. [12] investigated the use of neural networks in predicting traffic flow. One of the major advantages of the heuristic models is the computational requirements and CPU time are relatively small. Moreover, this approach is flexible in specifying the projected flow pattern given information up to the current time interval. The flexibility arises from the ability to formulate different heuristic rules corresponding traffic flow patterns in recent periods. The criteria for determining appropriate projection profile can be based on an expert system.

4 Functional requirements and capabilities of prediction models

Table 2 summarizes the major functional requirements and capabilities for on-line prediction models. These requirements and capabilities are presented based on the applications of prediction models for ATIS and ATMS systems. Furthermore, a comparison of the four types of prediction models is given. Depending on the application purpose, some prediction models may be more suitable than others. Specifically, DTA models have superior solution properties, but are complex to develop, have substantial computational requirements, and are difficult to understand. Statistical models have their advantages: they are relatively easy to develop, have small computational requirements, and permit understanding even to the novice. The major drawback of statistical models is that they cannot perform network-wide prediction. Simulation models are relatively easy and have medium-to-large computational requirements. But their major drawback is that no dynamic route choice behaviour is considered. Thus, their application in traffic prediction is limited to well-defined motorway segments or corridors where route choice is not applicable. The major advantages of the heuristic models are that the computational requirements and CPU time are relatively small, and the approach is flexible. However, the major drawback is defined by its own nature – lack of well-defined solution properties and the use of heuristic criteria only.

Table 2 Functional requirements and capabilities of prediction models

	DTA Model	*Statistical Model*	*Simulation Model*	*Heuristic Model*
• Representation of Network Traffic				
- Flow conservation/propagation	√		√	
- Queue, oversaturation and spillback	√		√	
- First-In-First-Out (FIFO)	√		√	
- Background traffic	√		√	
- Travel time functions	√	√	√	√
- Traffic signals/ramp controls	√		√	
- Temporal travel demand and supply	√		√	
- Capacity changes from incidents	√	√	√	√
• Traveller Behaviour/Characteristics				
- Dynamic user-optimal (DUO) route choice	√			
- Multiple classes of travellers: ATIS equipped vehicles, knowledge of network, age, compliance, etc.	√		√	
- Multiple classes of drivers: aggressive, cautious, etc.	√		√	
- Multiple classes of vehicles: car, truck, bus, HOV (restricted use of lane/roads)	√		√	
- Utility functions: weighting travel time, operating cost, preferences	√			
- Fixed route	√		√	
- Stochastic DUO route choice	√			
Theoretical Foundation				
- DUO route choice models (Time-dependent shortest-path and routing coordination under congestion)	√			
- Routing based on current and predicted conditions	√			
- Stochastic DUO: randomness of link travel times or capacities, knowledge, compliance, perceptions, etc.	√			
- Departure/arrival time choice	√			
- Mode choice and destination choice	√			
• Computational Issues				
- CPU times: (a) short, (b) medium, (c) long	(b)-(c)	(a)	(b)-(c)	(a)
- Hardware platform: workstation, PC	√	√	√	√
- Memory requirement	large	small	large	small
- Applicable networks	large	N/A	small	N/A

Table 2 Functional requirements and capabilities of prediction models (continued)

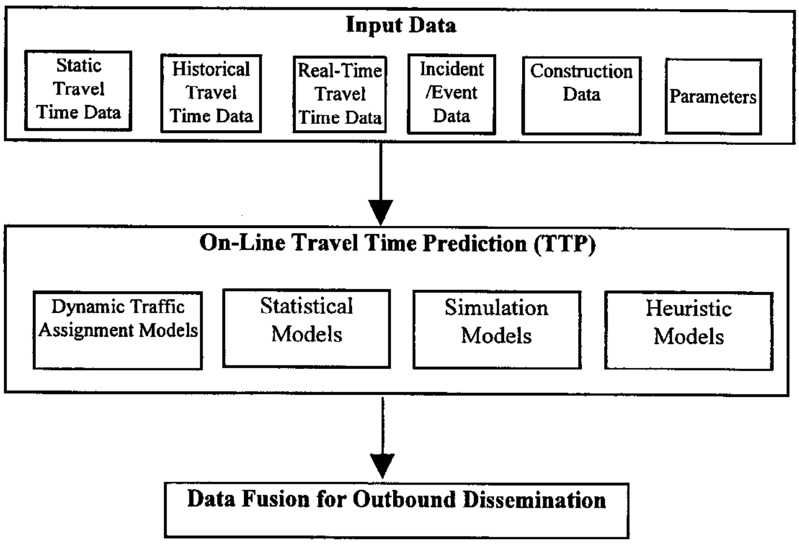
	DTA Model	*Statistical Model*	*Simulation Model*	*Heuristic Model*
• Deployment/Application: How can Traffic Information Centre (TIC) use these models?				
1. On-Line Application				
a) Real-time information acquisition and assimilation	√	√	√	√
b) Fusion with other models for providing link travel times, queues and flows	√	√	√	√
c) Compatible with real-time ATMS control strategies (signal/ramp control)	√		√	
d) Interface with other ATMS/ATIS modules (incident detection, surveillance, signal/ramp control)	√	√	√	√
e) Adaptable to various TIC/TMC architectures (distributed, decentralized, centralized, etc.)		√	√	√
2. Calibration: adjustment of model output vs. real time data				
a. Self calibration	√	√	√	√
b. Rolling horizon procedure	√			
• Future Potential Applications				
- Combined prediction and traffic control/coordination	√			
- Combined prediction for intermodal networks	√			
- Prediction under congestion pricing	√			

5 A general traffic prediction procedure

Travel time prediction is the major task of the on-line traffic prediction. To serve this on-line traffic prediction purpose, various input data must be prepared, including databases of static, historical, and real-time link and route travel times. The static link travel time can be estimated by using the link travel time functions or a static traffic assignment model. The route travel time is calculated by adding the static link travel times of the links comprising the route. Subsequently, the historical link travel time profile can be estimated by using the historical detector occupancy data or other data collected. A time series model could be used to serve this need. The real-time link travel time can be estimated by using detector occupancy data or other real-time data. The route travel time is calculated by adding the current link travel times over the route. Thus, the route travel time is instantaneous travel time based on prevailing traffic conditions. This is what is used in current practice in traveller information provision.

As shown in Figure 2, when the incident data and construction data are prepared, the on-line prediction can start. The incident/event and construction activity will significantly affect the travel time prediction and result in modifications of some of the prediction models. Furthermore, to use any of the four types of prediction models, the input databases required could be different. The associated parameters are also significantly different. For example, when a dynamic traffic assignment model is used to design this prediction module, a time-dependent O-D matrix is required, which is normally not available for the highway network and should be estimated. Sometimes, a combination of the four types of prediction models could be used in one Traffic Information System. For such a scenario, a data fusion process is needed to integrate the output from different traffic prediction models.

Figure 2 Travel time prediction in a traffic information system



Moreover, in order to produce more reliable and accurate predictive travel time information for travellers, a fusion process is necessary to integrate static, historical, real-time, and predictive travel times. This data fusion process could use a fuzzy logic model and take several steps. For instance, the first step in the fusion process is to fuse static and historical link travel time data. The static database normally has a full coverage of the highway network, while the historical database may have sparse coverage of the highway network. In other words, this fusion process is to improve some of the travel time estimates of the static database by using the partial historical database.

There are various real-time travel time information sources for a highway network, including loop detectors for sensing vehicles, video cameras, and probe vehicles. Some links of the highway network may have overlapping coverage of several real-time information sources, while other links may have only one real-time information source, or may not have real-time information sources at all. This step is to fuse these on-line real-time link travel time data together in order to provide a more complete coverage of the highway network.

Since only one part of the highway network links have on-line travel time data, the travel time prediction models could be used to generate meaningful dynamic estimates and predictions for all highway network links. This step is to fuse the above two databases together in order to produce a new dynamic database which has the full coverage of the highway network.

The final step is to construct a dynamic forecast which is equivalent to estimating the difference between static/historical and dynamic travel times. Since future static estimates will be known in advance, the final dynamic travel time forecasts will be generated by fusing static/historical estimates and dynamic estimate/prediction. This dynamic forecast database could be used for outbound dissemination.

6 Concluding remarks

This paper reviewed current practices of traveller information provision and provided some perspectives regarding the possible near term milestones in traveller information provision. To provide predictive traveller information in the near future, various prediction models are needed. This paper reviewed four types of prediction models:

1 simulation models

2 dynamic traffic assignment (DTA) models

3 statistical models

4 heuristic models

The simulation model simulates microscopic vehicle movement or macroscopic flow movement on links and in a network so as to calculate traffic flows and travel times. The DTA model estimates and predicts route flows and route travel times by using time-dependent O-D matrices, travel time functions, and assumed traveller route choice behaviour. The statistical model predicts flows or travel times based on analysis from a single link or from multiple links. The heuristic model is similar to the statistical model, but is based on the formulation of heuristic prediction rules.

The functional requirements and capabilities of the four types of prediction models were discussed and summarized. Some of the advantages and disadvantages of these models were compared with reference to short-term travel time prediction. Furthermore, a comprehensive prediction procedure was presented, which combines the four types of prediction models.

This paper provided some insights into the current and near future traveller information provision. While it is hard to predict which prediction model will prevail in the future, it is generally expected that the DTA model and the statistical model would become the major prediction tools, and the simulation model and the heuristic model will provide a supplemental function in the short term traffic prediction. As shown in the functional requirements and capabilities, the earlier work only provides a foundation for prediction methods and concepts, and there is a considerable need for deeper investigation and further development of alternative approaches for short-term travel time prediction.

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