Study on Traveler Oriented Dynamic Traffic Assignment Problems

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Abstract—In the previously published work [1], we proposed a traveler oriented model which incorporates the traveler dynamics into the cell transmission model (TOM-CTM). By taking travelers as the source of the traffic load, this model can be used to enhance existing CTMs. An open source macro-simulation tool (AuroraRNM), is used for experiments on a real road network. The results show that the TOM-CTM can reflect traffic dynamics properly and reasonably, provides a way to find out the manageable status in a nonequilibrium traffic, and is more practical than user or system optimal solutions. Based on this model, in this extended version, we explored the effect of historical traffic information (HTI) on the traffic. We discussed an HTI guided model (HTIGM) which uses the time dependent shortest path as the guidance. The further simulation results show that the HTIGM can provide another manageable way to guide the traffic flow by influencing the travelers’ choices and can be also used to spot the bottlenecks in road networks.

Keywords—Dynamic Traffic Assignment, Cell transmission model, Traveler dynamics, Nonequilibrium traffic, Historical traffic information.

I. INTRODUCTION

The dynamic traffic assignment (DTA) [2] model is one of the most important parts within a modern intelligent transportation system (ITS). Before the DTA model was proposed, the static traffic assignment model was widely adopted. But with the ever growing travel demand, the traditional static traffic model has failed to catch the traffic dynamics. Meanwhile, the imbalance between the demand and limited supply has become more and more serious, especially during the rush hours. Therefore the DTA model subsequently emerged, which focuses on studying the dynamic behaviors of the traffic flow.

Since Merchant and Nemhauser [3] first proposed a mathematical programming DTA model in 1978, the DTA problem has been studied for three decades. The model described in their seminal work, generally called the M-N problem has been studied for three decades. The model mathematical programming DTA model in 1978, the DTA the traffic flow.

The structure of this paper is as follows. The Section I is the introduction. The Section II gives descriptions and formulations of the model in details. The Section III deals with the numerical simulation and results analysis. The conclusions

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come with the last Section.

II. MODEL DESCRIPTIONS

A. Traveler Oriented Multiclass Cell Transmission Model (TOM-CTM)

In this section, the model proposed in [1] is presented before we could further discuss the effect of historical traffic information. Different from conventional CTM, demand in the TOM-CTM is divided into two parts: the traffic demand and the travel demand. The relationship between these two demand during each planning interval is formulated as equation (1), where \(d_{ij}^t(u)\) denotes the total demand of travelers from cell \(i\) to cell \(j\) that depart at \(t\) taking vehicle \(u\) and \(\hat{d}_{ij}^t(u)\) as the total demand of vehicles. Equation (1) means if travelers decide to travel with non-periodical vehicles (represented by \(u = 0\)), they may start their trips immediately and the traffic demand is equal to the number of travelers divided by the capacity \(\nu\) of each vehicle. Conversely, a periodical vehicle class, like a bus, has its own departing schedule that is static for a quite long time in spite of travelers’ quantities.

\[
d_{ij}^t(u) = \begin{cases} \hat{d}_{ij}^t(u), & u = 0 \\ \frac{d_{ij}^t(u)}{\nu}, & u > 0 \\ \end{cases} \tag{1}
\]

In order to simulate travelers’ boarding and dropping behaviors, additional features are added to conventional CTM. Fig. 1 shows a typical cascading scenario in a road network and travelers are assumed evenly distributed on the road and in the vehicles. More complex scenarios like merging and diverging can be easily formulated from it. In the figure, the solid lines show the traffic direction and \(\hat{y}_{ij}^t(t)\) above the lines denotes the number of travelers traveling from cell to cell. Based on the evenly distributed assumption, \(\hat{y}_{ij}^t(t)\) is calculated by equation (2), where \(N_i^j(t)\) denotes the number of travelers in \(n_i^j(t)\) vehicles and \(\hat{y}_{ij}^t(t)\) denotes the traffic flow.

\[
\hat{y}_{ij}^t(t) = \frac{N_i^j(t)}{n_i^j(t)} \hat{y}_{ij}^t(t)
\]

![Image showing the flow of travelers and vehicles between cells.](image)

Fig. 1: The flow of travelers and vehicles between cells.

\(n_i^j(t)\) and \(\hat{y}_{ij}^t(t)\) in equation (2) can be calculated based on any CTM implemented with multiclass characteristics, like [9] or [14]. For \(N_i^j(t)\), it is updated by equation (3) according to three parts: the travelers leaving the cell, the valid travelers entering the cell and the new travel demand.

\[
N_i^j(t+1) = N_i^j(t) - \hat{y}_{jk}^t(t) + \left[1 - q_{ij}^t(t)\right] \hat{y}_{ij}^t(t) + \min \left\{ w_{ix}(u) \hat{d}_{ix}^t(u), \nu n_i^j(t+1) N_i^j(t+1) \right\}
\]

Similar to \(N_i^j(t)\), \(\hat{y}_{ij}^t(t)\) is also updated by equation (4) according to three parts. The key point is to recalculate the number of travelers heading to each following station according to the in-travelers, out-travelers and new-travelers.

\[
\hat{y}_{ij}^t(t+1) = \frac{\hat{y}_{ij}^t(t)\left[N_i^j(t) - \hat{y}_{jk}^t(t)\right] + \hat{y}_{ij}^t(t)\hat{y}_{jk}^t(t) + '}{N_i^j(t+1)}
\]

Where the new travelers increment \(\prime\) is calculated by equation (5) in which \(\hat{y}_{ij}^t(t)\) denotes the proportion of travelers from cell \(i\) to \(j\) at time \(t\) choosing vehicle class \(u\).

\[
\prime = \sum \frac{\hat{y}_{ij}^t(t)}{\nu} d_{ij}^t(u) \nu \min \left\{ \sum \frac{\hat{y}_{ij}^t(t)}{\nu} d_{ij}^t(u), \nu n_i^j(t+1) N_i^j(t+1) \right\}
\]

More information about TOM-CTM can be found in reference [1].

B. Historical Traffic Information

In order to study how historical traffic information exerting an effect on traffic, let us consider the following scenario. ITS is used to help us find out which routes are congested constantly through analyzing the historical traffic data, and then provides the information to the travelers as a guidance. A proportion of travelers are very likely to choose different routes according to the guide in order to bypass those congested roads. It is based on the belief that if a specific route is congested for some period of time, it is more likely to be congested again for the same period of time in the following days because most of travel demand is derived from travelers’ daily regular activities, such as going to work from home or vice versa. Let us call this regularity as the traffic pattern. Obviously, the travelers’ choices determine the traffic pattern, and the traffic pattern will, in return, affect the travelers’ choices.

One intuitive way to guide travelers is to provide historical shortest paths with different departure time that is called the time dependent shortest path (TDSP). But to quickly obtain the TDSP is not an easy job and needs a powerful capability of analyzing the huge historical traffic data collected by various sensor systems, so we implement a distributed algorithm to solve the all-to-one TDSP problem for all departure time based on the dynamic shortest path optimality conditions [22]. The algorithm is implemented by MapReduce [23] which makes the algorithm easy to deploy on a convenient and scalable data processing platform. The algorithm details will not be discussed in this paper due to limited pages, but how it works in a historical information guided model (HTIGM) will be included in the experimental section. Fig. 2 shows the complete procedure of HTIGM.
1. InverseAdjacencyListMR is a MapReduce procedure that converts the data structure in the file containing the cost of each link to the adjacency list.

2. The adjacency list is taken as the input of TDSP algorithm in our works, and the time dependent results are passed to the next module. Only directly adjacent node on the shortest path is stored here rather than full path’s.

3. ShortestPathResultsConverter extracts and caches the full shortest path between each two nodes from above results.

4. ShortestPathAdapter gets the specific shortest path from cache according to the query.

5. TntpFileProcessor calculates split ratios according to the origin-destination (OD) demand and travelers’ choices (such as 20% of travelers accepting the historical information), and output an AuroraRNM configuration file in term of network topology, OD demand and split ratios.

6. AuroraRNM loads the configuration file and runs the simulation. Its results are stored as the input for the first step, and then do it all over again according to the travelers’ choices.

III. MODEL STUDY

For simplicity, it is presumed that the travel time is the most concerns of all travelers. It means that travelers will preferably choose vehicles that run on the corresponding shortest path. Then the simulation results of above traffic pattern will be regarded as the historical traffic information for the subsequent studies. The SiouxFalls network [24] is used for experiments, which is a typical test network adopted in many literatures. This network consists of 24 nodes and 76 links. On-ramps and off-ramps are added in order to handle the demand entering and leaving the network. In the following experiments, we discuss on how the proportion of travelers who accept the historical information changing influences the traffic status.

Fig. 3 shows the delays for different proportions, where HTIGM_20 denotes there are 20% of travelers following the historical information guide, i.e., these travelers following the time dependent shortest paths, but the 80% of travelers sticking to their choices. Because HTIGM_0 means no one accepts the information, its results are exactly the same as before. It can be seen from the figure when there are 40% of travelers choosing to follow the shortest path calculated from the historical traffic data, the delay of the entire road network is effectively reduced. After that, even more travelers choosing to follow the guide will not have obvious effects.

The heavy delay in HTIGM_0 is not only because there are too many vehicles on some routes, but also some of congested routes can be run through rapidly but cannot bear too much traffic load. Therefore, more travelers following the guide will help the traffic flow avoid these bottlenecks and finally reduce the delay. But delay only reflect how congested a road is, when more than 40% of travelers following the guide, the total travel time will definitely fluctuate because more and more travelers take circuitous routes.
in order to get some minor improvements) they can make. For example, 2 travelers per vehicle would be the most appropriate choice when planning the HOV lanes in the first scenario, and guide 40% of travelers to other routes according to the historical information to minimize the congestion in another scenario.

However, the decoupled demand in the TOM-CTM needs more calculation work for preparing traffic data, which is almost an unrealizable job before. But the latest advances in IT technologies bring forward the possibilities. Traffic data now can be easily collected, stored and processed with the help of the technologies such as the Internet of Things and the Cloud Computing. The HTIGM does show the feasibility to apply the historical traffic information to the real world. However, only the historical information is not enough to generate the automatic guide which does not need the intervention of the traffic management center, as travelers themselves are unable to know the proportions of choices at any time without real time information. This issue will be addressed in future works.

IV. CONCLUSION

The real world’s traffic is hard to reach the equilibrium status, like user optimal or system optimal status. Because in order to operate the optimal solution to the real traffic, many actions along with manpower, physical and financial resources should be taken. The proposed model is more practical for the TMC to apply not only because it can reach an acceptable status based on the nonequilibrium traffic, but also because it catches dynamics of the key subject of the traffic management (i.e., travelers). In the real world, the traffic managers could leverage the statistics of travelers, such as total demand, vehicle preferences, public transit schedules, etc., then use the model to predicate traffic load and find out the most appropriate status (when no more efforts are necessary to put

Fig. 5: Travel time on the static shortest path of node 19→1 under free flow

Fig. 6: Travel time on the time dependent shortest path of note 19→1

REFERENCES


