DYNAMIC ROUTING DECISIONS FOR COMMERCIAL VEHICLE OPERATIONS BASED ON REAL-TIME TRAFFIC CONDITIONS

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ABSTRACT: The application of the ITS (Intelligent Transportation Systems) technologies to facilitate the freight mobility requires dynamic routing decisions to reduce operational costs and enhance service levels. While most route planning or scheduling methods studied in the literature assume fixed or static travel times of the networks, this paper attempts to focus on the dynamic routing decisions in response to the real-time information. A microscopic traffic simulation model coupled with a link-to-link shortest path searching with turning penalties is suggested and developed to evaluate the potential benefits of the dynamic routing decisions, which considers both updated link travel times and detected incident conditions. The simulation results are described and discussed in this paper. Some interesting issues for future research needs are recommended. This research will help logistics companies to assess the benefits of the routing advisory systems for their day-to-day operations.
INTRODUCTION

Although the routing problems have been studied in the literature extensively, most of the studies focused on the static route planning or scheduling, i.e. the traffic conditions are assumed to be invariant with time. Very little research has been conducted to enable dynamic en-route decisions based on the constantly time-varying traffic conditions, where the travel time often changes rapidly, due to non-recurring congestion caused by incidents and non-scheduled lane-blocking events.

Advances in communication, automatic vehicle location, and geographic information system technologies have made available several types of real-time traffic information available to benefit the operations of commercial vehicles. Automatic vehicle location (AVL) system and two-way communication devices have enabled the fleet dispatcher to identify the current location of trucks and to communicate with the drivers in real-time. With this real-time information, the fleet dispatcher can respond to the changes of the vehicle locations and the traffic network conditions dynamically, making online decisions on a continuing basis to optimize the fleet performance, so as to reduce the travel time, to enhance the efficiency of energy utilization and to improve the overall level of service of the fleet operation.

However, the potential of such technologies has not been fully acknowledged either by the trucking companies or the logistics operators. The results of a previous survey (1) have indicated that almost 60% of the major carrier fleets in California are equipped with the advanced location-communication devices such as AVL, electronic data interchange, and mobile communication devices; but only a few of them actually make use of these technologies efficiently to support the decision-making of fleet management.

Although a few researches (2-5) have tried to address the aforementioned issue, the focus was on the en-route diversion strategies in response to unfolding customer demands. Conversely, the focal point of this paper is about the sound diversion strategies under rapidly changing traffic conditions.

To help the logistics companies and freight transportation operators to assess the potential benefits of such technologies, this research seeks answers to the following questions:

1. What is the usefulness of current sources of traffic information to the Commercial Vehicle Operations (CVOs)?
2. How the currently available traffic information could be used to enable routing and dispatching for commercial vehicle operations?
3. How much benefit will accrue from the provision of prevailing traffic information?

To this end, a microscopic simulation model embedded with dynamic re-routing strategies is developed in this research to evaluate the benefits of such diversion strategies in response to real-time traffic information. Both (a) the experiment scenarios modeled after a real road network and (b) the selected results derived from simulation are described. The findings of this research indicate that re-routing strategies with real-time information improve the fleet operational performance and will reduce the operation costs for logistics companies.

Followed by this introductory section, it is a detailed discussion of the methods of investigation, i.e. a hybrid simulation approach, a link-to-link shortest path algorithm with turn penalties, simulation programming and a real road network for simulation experiments. Subsequently, it is a section that illustrates the experimental scenarios, examines the simulation results and evaluates the performances of the diversion strategies proposed by this study. Finally, the concluding remarks and needs for future research are presented.

HYBRID SIMULATION APPROACH

In this research, a hybrid simulation approach, consisting of a high-performance customized microscopic simulation model for modeling trucking fleets, embedded with a routing decision model to provide optimal routing and diversion plans, is proposed (See FIGURE 1). The average link travel times are estimated through the simulations for every sixty seconds. Note that the length of the time interval is adjustable. The routing decision model calculates the optimal routing plan using the updated average link travel times from the microscopic simulation model. The routing decision model therefore incorporates the dynamic travel times and adjusts the routing plans according to the real-time traffic conditions.

LINK-TO-LINK SHORTEST PATH ALGORITHM WITH TURN PENALTIES

The shortest path algorithm has been intensively studied in the literature. Since the 1950s, a number of shortest path algorithms have been proposed (6-14). In general, there are two types of methods for solving the shortest path problems: label-setting and label-correcting. The label-correcting method is usually more efficient for sparse networks such as an urban road network (15,16). As a matter of fact, the nature of the shortest path problem considered in this research is indeed a single origin/single destination problem. As known, the label-correcting
approach is not able to ensure that better paths will not be discovered before the entire search procedure is completed (17,18). On the other hand, the label-setting approach will stop the shortest path search once the destination node becomes permanently labeled. In view of the purpose of applying the shortest path algorithm, in this research, adopting the label-setting approach will save the computational time significantly.

Typically, the origin and destination are considered as nodes in the shortest path algorithms. The shortest paths found by such algorithms are thus the node-to-node (or node-based) shortest paths. However, for a real road network, the intersections are usually represented as nodes while the roads or streets are usually represented as links in the shortest path algorithms. In the microscopic simulation in this research, the vehicles are able to adjust the route choices from their current positions, which are often located on roads/streets rather than at intersections. Hence, it could be more reasonable to consider the origin and destination as links in the shortest path search. Furthermore, the characteristics of the real road networks such as the one-way links and turning restrictions imposed by traffic signal control or regulations would also prefer the shortest path algorithm based on links rather than the ones based on nodes. For example, there are usually some turning restrictions imposed at the intersections and very few shortest path algorithms in the literature have thus far incorporated the turn penalties at each node into consideration. The traditional node-based shortest path algorithms are not able to differentiate the physically connected but operationally prohibited movements. Though such a drawback can be avoided by expanding each turning movement as separate links via the so-called expanded network representation, such expansions unavoidably will incur the increase in network scale. To this end, in order to take the turning restrictions and penalties into proper accounts, a link-to-link (or link-based) shortest path algorithm is proposed and adopted. It is based on the label-setting approach, Dijkstra’s algorithm (9).

The proposed algorithm maintains and adjusts a candidate list $V = (d_1, d_2, ..., d_n)$ but is different from Dijkstra’s algorithm in that each $d_j$, called the label of link $j$ (rather than the label of node $j$), is either a scalar or $\infty$. $(a_1, a_2, ..., a_n)$ is the link cost of each link. In addition, this algorithm exploits another cost, incurred by the turn penalties from each link to its outgoing links: $T_{ij}$, i.e. the turning cost from link $i$ to link $j$. In this study, $T_{ij}$ as well as the link travel cost $(a_1, a_2, ..., a_n)$ are calculated and updated through simulation.

Initially, (link 1 is assumed as the origin)

$$V = \{1\}$$

$$d_i = 0, \quad d_i = \infty, \quad \forall \quad i \neq 1.$$  

The approach proceeds in iterations and terminates when the destination link is removed from list $V$. A typical iteration (assuming $V$ is nonempty) is as follows:

\begin{verbatim}
Do while $V$ is not empty

Removed from the candidate list $V$, link $i$ such that

$$d_i = \min_{j \in V} d_j$$

If ( $i$ is the destination link ) stop the iteration;

Else

For each outgoing link $j$ from link $i$, if $d_j > d_i + a_j + T_{ij}$, set

$$d_j = d_i + a_j + T_{ij}$$

And add $j$ to $V$ if it does not already belong to $V$;

\end{verbatim}

Using this algorithm and the link travel time updated through simulations, the shortest paths of all interested vehicles, from their current positions to their destinations can be obtained.

API PROGRAMMING FOR CONTROLLING INDIVIDUAL VEHICLES

A microscopic traffic simulation model, Paramics, is adopted in this research. However, just like other simulation software, using Paramics to dynamically control and simulate the routing behavior of individual vehicles is not known as a straightforward process. In Paramics, a vehicle keeps a two-node look ahead for its route-choice decision (19). This means that at the point when a vehicle is released, the vehicle looks to see which turning movement it
should make at the end of its current link and the end of the subsequent link. As a vehicle is transferred from one link to another, the vehicle then updates its look ahead so that the vehicle will always know the next two links to travel.

To aid the routing and lane choice decisions in Paramics simulation, the Paramics software projects a dummy vehicle to some future point in the network (usually one or two links ahead of the source vehicle’s current position). This means that for the call for the routing decision function in Paramics, the software will actually return the dummy vehicle structure that is specifically created for the purpose of routing decision instead of returning the source vehicle structure. In this research, to control the routing behavior of individual vehicles during the simulation, an Application Programming Interface (API) program is developed. This API controls individual vehicles through the associated dummy vehicles based on the updated routing decisions at any instances during the simulation.

THE STUDY NETWORK

A portion of the Central Business District (CBD) network in Singapore, which is bounded by the Electronic Road Pricing (ERP) gantries, covering an area of approximately 3.0 km by 2.5 km is used for the simulations conducted in this research.

For the network coding, the details of the geometry and physical layout of the roads were collected via field surveys including the information such as the number of lanes (mid-block and at intersections), turning restrictions, post speed limit, etc. The data of signal timing and phasing, origin-destination (OD) statistics and information on the demarcation of zones in the CBD area were collected by related transportation authorities.

As shown in FIGURE 2, the network consists of 894 nodes (inclusive of 113 signalized intersections), 2,558 directional links and 100 traffic zones. The CBD network was chosen not only because it is a popular location for city logistics activities but also because the CBD consists of a high density of roads. There exist many alternative route choices in the CBD as connectors to other road networks such as the expressways or intercity corridors where the network structure is relatively sparse and where the links are usually long in distance and without many route choice alternatives. Hence, the performances of various diversion strategies can be better highlighted using the CBD type of urban network.

SIMULATION SCENARIOS, DIVERSION STRATEGIES AND RESULTS

The simulation experiments are conducted for the traffic conditions with and without incidents as well as the movements of commercial vehicles with and without in-vehicle route guidance (or advisory) systems. First, normal traffic operations without incidents were simulated to provide the benchmark. Subsequently, the scenarios of dynamic routing decisions based on different sets of traffic information provisions were studied. For each one of them, the effects of traffic operations with incidents but without real-time in-vehicle guidance were examined. Thus the increase in average total travel time due to an incident is estimated. This is followed by an experiment with the provision of real-time in-vehicle information and route-guidance systems using the corresponding diversion strategy. The potential benefits and limitations of the diversion strategies under each scenario are then evaluated. During the simulation, the link travel times for routing purpose are refreshed at every sixty seconds.

In the simulation experiments, there are 50 trucks sending across the CBD from point I to point O (See FIGURE 2) with a relatively even time interval at between 17:00 and 18:00 hours. For benchmarking purpose, the simulations under normal traffic conditions without incidents show that the total travel time for the 50 trucks to travel across the CBD was 26,188.0 seconds, i.e. an average of 523.8 seconds per truck.

Scenario 1

The corresponding diversion strategy adopted for this type of traffic information is the proposed link-to-link shortest path algorithm based on the updated link travel time. Three different incident locations, as shown by three triangles in FIGURE 2, are at the upstream, middle and downstream of the route being examined. The incidents start from 17:05 hours while the variations for the duration of the incidents were 5, 10, 15 and 20 minutes, respectively. The simulation results are illustrated in TABLES 1-3 and FIGURES 3-5.

This scenario considers the route guidance system without the information on how long the current congestion would last, while taking the link travel times as its only decisive variable. When an incident occurs, the link speed begins to decrease and even goes down to zero at certain moments. Hence, the guidance system based on such a strategy would suggest a diversion plan at any point where the travel times of alternative routes are less than that of the existing route.
TABLES 1-3 and FIGURES 3-5 show that in most cases this diversion strategy yields improvement in terms of the average fleet travel time. This is because in this scenario, the CBD network offers many choices to divert a vehicle from the incident location, that a good alternative route may only cause a small addition to the travel cost.

This simple strategy fails when the incident occurs at the middle part of the initial route and lasts for a shorter duration such as 5 minutes and 10 minutes (see TABLE 2 and FIGURE 4). This means that in this network, the alternative routes available near the middle part of the route will incur a higher travel time than waiting in the queues cause by the incident for 10 minutes, while the incurred travel times for diversions taken at the other two places (upstream and downstream) in the network are quite low.

The results also show that the average travel times of the circumstances with and without the route guidance systems increase due to the increase in incident duration. Although the improvement of the average travel time increases with the incident durations, the percentage of the improvement of the average travel times does not necessarily grow accordingly (See TABLE 3 and FIGURE 5). This is because the affected number of trucks is different. Likewise, the diversion times, locations and diversion plans of the affected trucks might also be different over time as the trucks undergo the constantly changing traffic conditions of the CBD network. (e.g. one possible reason may be that the traffic conditions of the corresponding areas, including the alternative routes for diversion, have become worse with the increasing duration of an incident.)

Generally, the above results illustrate that the decision for diversion is mainly related to the road network structure around the incident location. If an alternative route, which only induces a lower travel time than that caused by the congestion, is always available, even a simple diversion strategy lacking the information of the encountered incidents will work.

Scenario 2

In this scenario, the information of the prevailing travel time of each link is readily available, and at the same time the forecast on the duration of the encountered incident is also reliable. The corresponding diversion strategy adopted here is based on the proposed link-to-link shortest path algorithm utilizing the updated link travel times and a reliable estimation of how long the incident or congestion would last.

This simulation scenario demonstrates that the decision-maker has a good understanding of real-time link travel times and the duration of the encountered incident would last. This diversion strategy takes both the link travel time and the incident duration into consideration. The simulation results reveal a consistent improvement in average travel time at all three locations (upstream, middle, downstream). At certain instances of this test network, when there exist no alternative routes for travel time savings for the vehicle to get away from the encountered incident, this re-routing strategy would advise the users to stay in the congestion rather than taking diversions (See results in TABLE 4 and FIGURE 6).

CONCLUSION

This research identifies and explores the potential employment of real-time traffic information for the efficient management of city logistics operations. Two scenarios, based on different sets of traffic information provisions with their corresponding strategies, are illustrated. Simulation results suggest that the diversion strategies examined usually result in reduced travel times and hence improve the efficiency of commercial vehicle operations.

Presently, as the availability of AVL and two-way communication technologies improves, and as the costs for vehicles to be equipped with these technologies decrease, more and more fleets will incorporate these technologies into their daily operations. This research will help the logistics companies to assess the benefits of getting in-vehicle route-guidance (advisory) systems in their day-to-day operations.

SUGGESTIONS FOR FUTURE RESEARCH

To further analyze and evaluate the performance of dynamic diversion strategies towards different kinds of network traffic conditions, some directions for future research are proposed.

The proposed diversion strategies can be considered as the class of greedy strategies because they are based on the current traffic conditions, i.e. the instantaneous link travel times. It may be argued that under such kinds of myopic or greedy strategies, the route guidance systems may consistently suggest diversion plans at any point where the alternative route choice is better than the one is being used. Given the rapid changing traffic conditions, excessive diversions may arise and cause a sort of “zig-zag” effect; therefore, the instantaneous travel time based
diverting strategies may lead to higher travel times, which might sometimes be even worse than the original routing plan.

Thought the diversion strategy in this research is based on prevailing link travel times and the incident durations, it has been proven to be effective in the sense of arriving at workable diversion strategies. It is true that the diversion strategy should depend on the network traffic conditions. When the traffic conditions are in a relatively stable state, a simple re-routing strategy based on the prevailing/instantaneous travel times may have been sufficient. While under dramatically fluctuating traffic conditions, more sophisticated re-routing strategies such as the one based on predictive travel times will need to be developed and a time-dependent shortest path algorithm will also be needed to fulfill the more complicated re-routing strategies, as compared with the one based on simple instantaneous travel times. To this end, there at least exist two interesting research questions:

1. Is the prevailing/instantaneous travel time adequate in supporting the needs of diversions?
2. How much benefit would be achieved through the use of predictive travel times as compared with the instantaneous travel times?
REFERENCES


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<td>Simulation Results under Scenario 2 with Incident at the Middle Part of the Route</td>
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### TABLE 1 Average Travel Time under Scenario 1 with Incident at the Upstream of the Route

<table>
<thead>
<tr>
<th>Incident duration</th>
<th>5 min</th>
<th>10 min</th>
<th>15 min</th>
<th>20 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>With guidance system</td>
<td>569.2 sec</td>
<td>616.1 sec</td>
<td>681.7 sec</td>
<td>721.5 sec</td>
</tr>
<tr>
<td>Without guidance system</td>
<td>571.5 sec</td>
<td>720.4 sec</td>
<td>926.5 sec</td>
<td>1044.5 sec</td>
</tr>
<tr>
<td>Improvement by guidance</td>
<td>2.3 sec</td>
<td>104.3 sec</td>
<td>244.8 sec</td>
<td>323.0 sec</td>
</tr>
<tr>
<td>Improvement %</td>
<td>0.4 %</td>
<td>14.5 %</td>
<td>26.4 %</td>
<td>30.9 %</td>
</tr>
<tr>
<td>Incident duration</td>
<td>5 min</td>
<td>10 min</td>
<td>15 min</td>
<td>20 min</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>With guidance system</td>
<td>601.2 sec</td>
<td>658.8 sec</td>
<td>704.9 sec</td>
<td>842.0 sec</td>
</tr>
<tr>
<td>Without guidance system</td>
<td>567.1 sec</td>
<td>653.7 sec</td>
<td>886.2 sec</td>
<td>1259.1 sec</td>
</tr>
<tr>
<td>Improvement by guidance</td>
<td>-34.1 sec</td>
<td>-5.1 sec</td>
<td>181.3 sec</td>
<td>417.1 sec</td>
</tr>
<tr>
<td>Improvement %</td>
<td>-6.0 %</td>
<td>-0.8 %</td>
<td>20.5 %</td>
<td>33.1 %</td>
</tr>
</tbody>
</table>
### TABLE 3 Average Travel Time under Scenario 1 with Incident at the Downstream of the Route

<table>
<thead>
<tr>
<th>Incident duration</th>
<th>5 min</th>
<th>10 min</th>
<th>15 min</th>
<th>20 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>With guidance system</td>
<td>564.3 sec</td>
<td>605.2 sec</td>
<td>661.6 sec</td>
<td>862.0 sec</td>
</tr>
<tr>
<td>Without guidance system</td>
<td>567.7 sec</td>
<td>712.6 sec</td>
<td>997.3 sec</td>
<td>1214.3 sec</td>
</tr>
<tr>
<td>Improvement by guidance</td>
<td>3.4 sec</td>
<td>107.4 sec</td>
<td>335.7 sec</td>
<td>352.3 sec</td>
</tr>
<tr>
<td>Improvement %</td>
<td>0.6 %</td>
<td>15.1 %</td>
<td>33.7 %</td>
<td>29.0 %</td>
</tr>
</tbody>
</table>
TABLE 4 Average Travel Time under Scenario 2 with Incident at the Middle Part of the Route

<table>
<thead>
<tr>
<th>Incident duration</th>
<th>5 min</th>
<th>10 min</th>
<th>15 min</th>
<th>20 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>With guidance system</td>
<td>567.1 sec</td>
<td>653.7 sec</td>
<td>704.9 sec</td>
<td>842.0 sec</td>
</tr>
<tr>
<td>Without guidance system</td>
<td>567.1 sec</td>
<td>653.7 sec</td>
<td>886.2 sec</td>
<td>1259.1 sec</td>
</tr>
<tr>
<td>Improvement by guidance</td>
<td>0.0 sec</td>
<td>0.0 sec</td>
<td>181.3 sec</td>
<td>417.1 sec</td>
</tr>
<tr>
<td>Improvement %</td>
<td>0.0 %</td>
<td>0.0 %</td>
<td>20.5 %</td>
<td>33.1 %</td>
</tr>
</tbody>
</table>
Dynamically get the MOE during the simulation

Optimal routing or diversion plan

Model for freight routing decision

Input data

Working cycle (e.g. 5 minutes)

Microscopic traffic simulation model

Updated traffic condition

FIGURE 1 Hybrid Simulation Approach
FIGURE 2 CBD Road Network in Singapore
Average travel time with/without guidance system

Incident duration (Minute)

Improvement (Sec)

Incident duration (Minute)

Improvement (%)

Incident duration (Minute)

FIGURE 3 Simulation Results under Scenario 1 with Incident at the Upstream of the Route
Average travel time with/without guidance system

Incident duration (Minute)

Average travel time (Sec)

Incident duration (Minute)

Improvement (Sec)

Incident duration (Minute)

Improvement (%)

FIGURE 4 Simulation Results under Scenario 1 with Incident at the Middle Part of the Route
FIGURE 5 Simulation Results under Scenario 1 with Incident at the Downstream of the Route
Average travel time with/without guidance system

Incident duration (Minute)

Average travel time (Sec)

with guidance system

without guidance system

Incident duration (Minute)

Improvement (Sec)

Incident duration (Minute)

Improvement (%)

FIGURE 6 Simulation Results under Scenario 2 with Incident at the Middle Part of the Route