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DYNAMIC FREIGHT TRAFFIC SIMULATION PROVIDING REAL-TIME INFORMATION

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ABSTRACT

The paper describes a prototype Dynamic Freight Traffic Simulation model called DyFTS, constructed for studying the effects of highly developed information technologies and logistic strategies on freight transportation. DyFTS is designed as a highly adaptable system that can be easily embedded into a more comprehensive transportation simulation model. Various decision-making processes are formulated, such as goods-to-vehicle assignment, departure time choice and pre-trip routing, and en-route vehicle redirection. As part of the modeling system, descriptive real-time information for the network is simulated to study the influence of such information on freight transportation. A knowledge-based learning process is established to refine the perceptions of decision-makers to the transportation network based on past experience. Numerical examples are designed to compare a set of freight movements operating both with and without the aid of real-time information, as such freight operations vary according to different delivery time requirements and using different fleet configurations.

1 INTRODUCTION

Efficient distribution of goods is of paramount importance in today's business, as transportation costs become a non-negligible part of the purchase price of most products in competitive markets. Such efficiency is achieved, in particular, through efficient routing and scheduling of the vehicle fleet that fulfills the distribution task.

Increasingly, information technology (IT) is being applied to the freight transportation industry as a means of better arranging shipments and utilizing commercial vehicle fleets. Besides these private sector advances and in support of them, the regional implementation of Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS) has provided more timely information for both pre-trip planning and en-route decision-making. Recent studies include those by Hu and Mahmassani (1997), Srinivasan and Mahmassani (1999), Mahmassani and Liu (1999), and Madanat et al. (1996), all of which deal with decision-making processes and real-time information involved in a dynamic vehicle scheduling environment, at topic of direct interest to this present study.

However, in all of these and related studies to date the operational features of each type of vehicle are assumed homogeneous, while drivers are assumed to be in complete control of their movements. In reality, this is not the case. For example, the drivers of heavy goods vehicles often must follow the orders of dispatchers whose job is to make pickup and delivery scheduling decisions. These dispatchers assign vehicles to different locations and even to specific routes based on the overall demand for services and, where information is available, on the traffic conditions on the network; while drivers may in turn report any changes in current traffic conditions to their dispatchers and await any new orders to be relayed to them. That is, both drivers and dispatchers are involved in the decision-making system. In such circumstances a driver's range of influence is often restricted to making a small detour to get gas or food, while dispatchers can control the whole operation of the vehicles from the very beginning of its daily delivery schedule to its return to the depot.

Of considerable current interest is the effectiveness of this sort of real-time information on an enterprise's freight operations. What is the value of such information? More specifically, does the high investment to construct such a real-time information system deliver the expected rewards? The federal government has also shown a great deal of interest in this tropic. For example, the Federal Highway Administration in recent years has provided a good deal of funding to develop both the DynaSMART (FHWA 2003) and DynaMIT (FHWA 2003) simulation and real-time traffic monitoring and control prototypes, albeit with the primary focus placed on passenger transportation. Although heavy vehicles such as trucks can also be simulated by such software the distinctions between the decision-making processes of commercially directed heavy vehicles and passenger vehicles are not explicitly pointed out. With the increasing use, and growing recognition, of freight vehicles as a non-negligible component of most of the nation's major traffic flows, it is worthwhile devoting specific attention to the study of freight traffic characteristics and trying to integrate it with our knowledge of passenger carrying traffic. The result will be a more complete representation of the way traffic flows both within and between urban systems.

Given the known complexity of modeling traffic movements, computer simulation has shown increasing applicability in current research and practice as highly advanced computation technologies provide more storage space and computational speed for the application of traffic simulation models. In this paper, a prototype dynamic freight traffic simulation model is described. Using this model it is possible to reproduce the traffic flow pattern of specific freight carrying vehicles under various scenarios, reflecting not only changing traffic conditions but also changes in the characteristics of the vehicles, including differences in the use of on-board, centrally managed IT technology. With the model it is possible to estimate the approximate value of such information by comparing the transportation cost for shipments before and after the real-time traffic information is provided. The paper builds on previously reported work by Xu et al. (2003), in which the idea of such a freight movement simulation is established within a multi-tiered network model that integrates the physical transportation network and its flows with logistic, financial, information networks, and their respective commodity, monetary and data flows. In this paper the stochastic freight traffic simulator presented in that earlier paper is further enhanced by adding more decision-making strategies into the system design. The result is a more powerful tool for the study of freight traffic movement patterns within a dynamic information retrieval and applications environment.

The rest of the paper is organized as follows. Section 2 describes the components of the dynamic freight traffic simulation model and the methodology underlying the development of each of its components. Section 3 then describes applications of the methodology to a small numerical example. Conclusions are drawn from the application results in Section 4 of the paper.

2 STRUCTURE OF DYNAMIC FREIGHT TRAFFIC SIMULATION

The dynamic freight traffic simulation system (DyFTS) simulates freight movements over the physical facilities represented by a transportation network in which the travel time on each link is allowed to change over time. The simulation begins with a fixed size fleet of heterogeneous vehicles located at a number of pre-specified origin locations. Each origin and each destination designated to receive freight has a time window during which a shipment can be served. The arrival time interval for each shipment is assumed to be provided by the customer, and if a shipment arrives outside this interval, a scheduled delay (early or late delay) penalty results. DyFTS simulates the dynamic process of transporting such shipments to their destinations, while satisfying the time window constraints placed on each shipment at each location. A fixed service time for loading or unloading goods is defined for each destination location. As an input, the shipments to be transported are based on a predefined set of orders. Those shipments received after a fixed time deadline, however, may be assigned to the next day's delivery. This order information is provided as an input to DyFTS. In practice it could be retrieved either from a related logistics system (Xu et al. 2003) or from other sources. A number of static shipments are assumed to be known at the start of each day's operation.

Within DyFTS only dispatchers are assumed to have instant access to the real-time information on traffic conditions over the network, while drivers are assumed to know little about traffic conditions other than those conditions on or close to the current link they are on. Drivers consequently do not have a global picture of the overall network traffic conditions, while dispatchers know far more about such conditions and can respond accordingly. For simplicity, the decision-makers in this system are assumed to be the dispatchers, not the truck drivers. Communication between the central dispatch office and the drivers can take place at any location in the network and at any time. The shipment routes may be modified frequently by dispatchers based on the real-time traffic conditions over the network.

The decision-makers involved in this freight movement system are assumed homogeneous, which means that they each have the same objectives and follow the same procedures when making decisions. DyFTS is designed as a discrete-event simulation system, allowing comparison of freight routing patterns (and eventually, modal selections) under different fleet and delivery time strategies. Therefore, the travel time on each link in every time step of the simulation, along with the timing of any incidents, is designed to be reproducible so that the results are comparable under different model inputs. Currently DyFTS is designed to simulate long-haul shipments, so that trip chaining is not yet considered in this system. The basic structure of this simulation system is shown in Figure 1.

2.1 Transportation Environment

The transportation environment refers to the design and operational characteristics of the transportation infrastructures over which freight vehicles travel. This component of the simulation model is responsible not only for generating the travel time on each link at each time step, but also for introducing various incidents into the simulation at specific times and locations in the transportation network. Any change in this network may influence one or more freight vehicle movements. The environment is generated by a

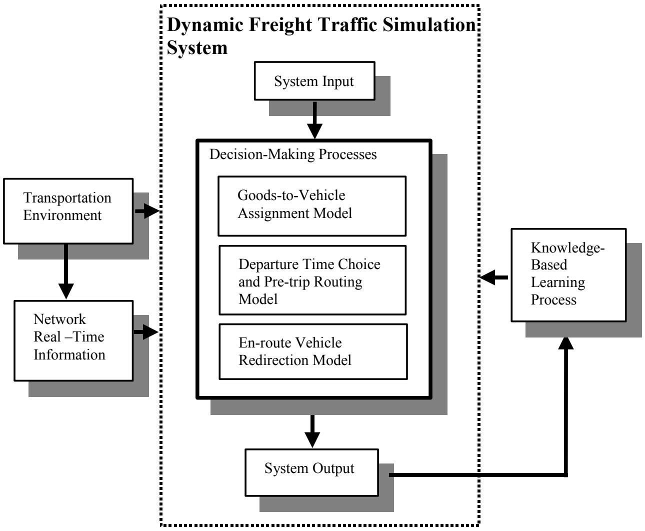


Figure 1: Structure of the Dynamic Freight Traffic Simulation System

dynamic assignment of travel times to the network links. A random incident generator is used to assign an incident of random severity to the network during the simulation horizon.

2.1.1 Dynamic Travel Time Simulation

In DyFTS travel time is the elementary parameter used to represent traffic conditions in the network. This parameter reflects both the normal daily dynamics of the network, and the impact of incidents. Travel times on different links can be correlated when certain circumstances are encountered. For example, traffic conditions may be affected by the weather: on a rainy, foggy or snowy day driving is likely to be more difficult, and therefore slower, in a certain segment of a road network. Traffic dynamics is measured in terms of both the mean and variance of link travel times, currently using the Normal distribution to capture link specific travel time variations. These variations are assumed link specific and independent (i.e. uncorrelated across different links) in the current simulations. This condition, as well as the statistical properties of the travel time distribution, can be changed in future simulations.

2.1.2 Incident Simulation

The environment simulation also contains an incident generator that stochastically assigned a certain number of traffic incidents with random severity levels to roadway links on each trial day. Incidents are used to simulate unexpected situations on the network. They usually cause significant changes in the freight carrying property of the network, and therefore affect the decision-making of the vehicle movement dispatchers. Links with incidents assigned have their link travel times automatically increased to represent the effects of the incident. Any congestion or other phenomenon induced by such incidents is then modeled or reflected by a change in the origin-to-destination travel times of those dispatched vehicles affected by the incidents. The occurrence of each type of incident is assumed to follow a Poisson distribution, and the corresponding interval between two adjacent incidents of the same type is an exponential random variable. The types of incidents currently being considered in DyFTS are vehicle crashes, link constructions or closures, and inclement weather. The distribution of each type of incident is assumed to be independent of the other two types. All incidents are confined to a specific link.

2.2 Network Real-Time Information

The model component shown as Network Real-Time Information in Figure 1 simulates the data provided by a region's current ITS system. It could be either descriptive (such as current travel time detected on certain links, link specific incident information, etc.) or prescriptive (such as route guidance) information. DyFTS only includes descriptive information at the present time. Descriptive information, such as incident locations and their corresponding severity (congestion) levels, is updated at a frequency predetermined by the analyst. Understanding the benefits of using such an information system to route and schedule freight vehicles is a key motivation behind the design of DyFTS. Real-time information will be purchased by decision-makers based on their perceptions on how well it facilitates and improves the results of their decision-making process. The value of providing real-time traffic information services can be evaluated in DyFTS by comparing the total travel cost before and after using such information. Other measures of benefit could also be developed. In addition, interaction effects between pre-trip and en-route information, between pre-trip and incident-induced congestion information, and between incident information with both pre-trip and en-route information can all be studied using this simulation model.

2.3 Knowledge-Based Learning Process

Decision-makers refine their perception of the network through a learning model which "learns" the environment characteristics (e.g., expected link travel time and its variance) based on past experiences. These experiences are then used to better organize the timing and routing of future shipments. In the following equations, $\overline{T}_{i,t}$ denotes the updated expected travel time on link i learned at time step t, $S^2_{i,t}$ denotes the updated variance of travel time on link i learned at time step t, and $T_{i,t}$ denotes the actual travel time on link i experienced at time step t.

$$\overline{T}_{i,t} = f_{\overline{T}}(T_{i,t}, T_{i,t-1}, T_{i,t-2}, ..., T_{i,1}), \qquad (1)$$

$$S^2_{i,t} = f_S(T_{i,t}, T_{i,t-1}, T_{i,t-2}, ..., T_{i,1}). \qquad (2)$$

This quite general model leaves a lot of room to introduce more specific learning rules and decision-maker responses based on the knowledge of historical data. In this paper the decision-makers use the following form of temporal information decay model (Xu et al. 2003).

$$\overline{T}_{i,t} = (T_{i,t} + \gamma T_{i,t-1} + \gamma^2 T_{i,t-2} + \ldots + \gamma^{t-1} T_{i,1}) / \sum_{s=1}^{t} \gamma^{t-s} \qquad (3)$$
$$= \sum_{s=1}^{t} \gamma^{t-s} T_{i,s} / \sum_{s=1}^{t} \gamma^{t-s},$$

$$S^2_{i,t} = [(T_{i,t} - \overline{T}_{i,t})^2 + \gamma (T_{i,t-1} - \overline{T}_{i,t})^2 + \ldots + \gamma^{t-1} (T_{i,1} - \overline{T}_{i,t})^2] / \sum_{s=1}^{t} \gamma^{t-s} \qquad (4)$$
$$= \sum_{s=1}^{t} \gamma^{t-s} (T_{i,s} - \overline{T}_{i,t})^2 / \sum_{s=1}^{t} \gamma^{t-s},$$

where $0 \le \gamma \le 1$, and where, as a result, the closer to zero this parameter value becomes, the less weight is given to previous (older) travel time information.

2.4 Dynamic Freight Traffic Simulation

From Figure 1, we can see that the core of DyFTS is its representation of the decision-making process, followed by the set of assumed homogeneous decision-makers. This process is responsible for simulating the over-the-road operations of the freight traffic. The major controls are the basic decision-making processes involved when transporting goods, i.e. goods-to-vehicle assignment, departure time choice and pre-trip routing, and en-route vehicle redirection.

2.4.1 System Input

System input includes (1) the network components (such as nodes and links) and their related information (e.g. capacity, free-flow speed), (2) shipment origin-to-destination (OD) information, and (3) vehicle fleet information. The network used in the simulation is constructed from the North American Intermodal Transportation Network developed by Oak Ridge National Laboratory (Southworth and Peterson 2001); shipment OD information is assumed to be external to DyFTS. This type of information can be based on observed OD data or derived by a suitable modeling process (see Xu et al. 2003). Fleet management is a big issue in freight transportation. DyFTS can be used to test the effects of different configurations of fleet vehicles on the performance of an enterprise's freight transportation business.

2.4.2 Simulated Entities and Discrete Events

Components of the system that require explicit simulation in DyFTS are defined as model "entities". In this paper these entities consist of the network components (nodes, links, etc.) plus transportation equipment (vehicles: truck, railcar, etc.). For each entity, both static and dynamic variables are used to describe entities' features and up-to-date state at different discrete time intervals (see Xu et al. 2003). DyFTS is designed as a discrete-event simulation system using a next-event time advance mechanism. An event is defined as an instantaneous occurrence that can produce changes in the system state. Two types of events are considered in the system, one is vehicle related (such as a vehicle entering or leaving a link), and the other is environment related (such as a crash occurring on a link). Such events in DyFTS describe and affect the evolution of freight movements (see Xu et al. 2003).

2.4.3 Transportation Cost

Transportation cost is the basic decision variable that directly influences the decision-making process in freight traffic routing. When routing a freight vehicle, several different objectives are considered, namely: minimize the total distance, and minimize the total trip time. The first objective can be considered when no fixed costs are associated with each vehicle. The time issues are addressed in the second objective, thus avoiding solutions with low distance traveled but large travel time. The latter appears to be a more realistic approximation of the fixed and variable costs found in practice. A third objective is to minimize the variance of shipment travel time. This objective seeks to decrease the fluctuations in travel time for specific trips by avoiding links with large travel time deviations or high incident occurrence rates (Cohen and Southworth 1999). In DyFTS the travel cost is constructed as an expected disutility function that incorporates these three objectives, using the following weighted summation:

$$LC_i = cD_i + \omega S_i + v\overline{T}_i, \qquad (5)$$

where:

LC_i = the transportation cost on link i;

D_i = the physical distance on link i;

S_i = the estimated standard deviation of travel time on link i, provided from learning model;

$\overline{T}_i$ = the estimated travel time on link i, provided from learning model;

c, ω, v = the weights placed on distance, travel time deviation, and travel time respectively.

The weights c, ω, v can be understood as the unit fuel and wear and tear cost, the travel time reliability penalty, and the travel time penalty respectively.

2.4.4 Goods-to-Vehicle Assignment

In DyFTS each origin is assumed to have a fixed but heterogeneous vehicle fleet size available for transporting freight to a region's various destinations. Shipments are assigned to the vehicles with a bias in favor of shipments with early arrival time windows. The earlier the expected arrival time a shipment has, the higher the priority it is given to be assigned to a vehicle. In addition, when an empty vehicle returns to the origin, a goods-to-vehicle assignment procedure is activated, allowing all available vehicles to be re-assigned to non-loaded shipments. When new shipments arise, available vehicles are assigned to these shipments in the order of their expected arrival time. Two objectives are involved in this vehicle assignment, due to the heterogeneous configurations of the fleet of vehicles equipped in each origin, which are:

Objective 1: To use the fewest number of vehicles assigned to transport a shipment.

Objective 2: To have the least amount of empty vehicle space in individual shipments.

This is a bi-objective problem, but with priority. Objective 1 is assumed to have a higher priority than Objective 2. Thus, when assigning goods to vehicles, the plan using the fewest number of vehicles is going to be selected as the final plan. If more than one plan satisfies this higher priority, then the plan that has the least volume of empty vehicle space will be chosen. One thing worth mentioning here is that transportation cost is not explicitly presented as an independent objective in this component of the model. Objective 1 above has already covered it.

2.4.5 Departure Time Choice and Pre-Trip Routing

The determination of departure time for a shipment is closely associated with pre-trip routing logic and total expected travel time. In DyFTS, the expected arrival time for each shipment is assumed known. This assumption stems from the fact that customers are assumed to impose service deadlines and earliest service time constraints. Links used by a shipment are selected in accordance with the estimation of the "best" route, i.e., the route of the least transportation cost. In DyFTS the total en-route travel cost of a shipment is the summation of the costs on all the links along the route. Based on Loui (1983), the mean and variance of a route-specific travel time is simply the sum of the mean and variance of travel time on all the links lying on the path respectively. Hence, the path, or route, can be described entirely in terms of the mean and variance of its link travel time for decision-making purposes. The departure time of a shipment equals the difference between the expected arrival time of the shipment and the mean travel time on the path. If the time variance along the path is larger than the customer-specific indifference interval of arrival time, then a scheduled delay penalty may arise.

2.4.6 En-Route Vehicle Redirection

When the predetermined departure time of a certain shipment is reached, the shipment enters the link and follows the planned route. Due to the perceived dynamics of traffic conditions and the randomness of incident occurrences, the predefined route may not remain optimal and may need to be adjusted for any changes in the prevailing traffic conditions (e.g. incidents). A vehicle redirection algorithm will be activated in this case. Once a vehicle departs from the origin, the traffic conditions on the links along the route need to be tracked frequently. The vehicle redirection checking procedure is activated when vehicles are at nodes. The procedure finds a route from the current node to the destination node based on the criteria of least transportation cost. The algorithm proceeds forward node-by-node until the destination is reached. A threshold is set to determine whether redirection is warranted or not, which excludes unnecessary operations due to the stochastic nature of the physical transportation network. The redirection threshold provides a condition to decline unreasonable redirection operations.

2.4.7 System Output

System output includes, among other things, updated shipment and trip records, link cost, and learning results. Based on these simulation results, various performance measures are statistically calculated, such as travel cost, travel time, travel distance, delay time, delay ratio and vehicle load factor. These measures can be calculated by shipment and by origin. Routing patterns can also be derived from the simulation results. The design of the simulation system allows the study of various aspects or strategies in freight transportation. For example, one can study the differences in performance measures and route patterns between scenarios transporting freight with and without the real-time information; the differences in performance measures associated with transporting freight with different delivery time requirements; and the effectiveness of different vehicle fleet configurations on freight operations at each origin, etc. Example applications are provided in the next section.

3 APPLICATIONS

The DyFTS described in the previous section provides a rich set of options with which to study the effects of various strategies on freight movements. The system is designed to be able to run on a large and detailed transportation network. It is implemented using the GISDK language supported by TransCAD 3.6 or higher developed by Caliper Corporation, with the following minimum system requirements:

- Pentium-compatible processor (Pentium III or higher recommended).
- Windows® 98, ME, NT 4, 2000, XP.

- 256 MB of RAM (512 MB recommended), and 37 MB of free hard disk space.
- 256-color monitor capable of 800 x 600 screen resolution.

Experiments have been designed to analyze the benefits and behavioral changes implied for freight movements in the presence of real-time information, of different delivery time requirements, and of different fleet configurations. The example network where freight shipments are simulated in this paper is a highway network composed of 11,158 links within the New England and New York State areas. A set of nine freight shipments was input to the simulation model. This data is composed of shipments from four freight generating origins locating in New York, Connecticut, and Maine respectively, and five freight receiving destinations, all in Massachusetts. In these simulation each origin is assumed to have vehicles readily available to transport goods, and that a single, homogeneous commodity is being shipped.

3.1 Base Case: The Performance Comparisons between Freight Shipments Provided and Not Provided with the Real-Time Information

In the base case, an experiment is conducted under two scenarios. In the first scenario, real-time traffic conditions on the transportation network, including the current travel time on each link and the occurrences and types of incidents, are assumed provided once every ten minutes for decision-makers to update their perception of the network and adjust shipment routes. In the second scenario, decision makers do not have current information on the network, except for travel times and incidents experienced by their own vehicles running over the network. The simulations under both scenarios are performed with one-day duration. The results are shown in Table 1.

The results in Table 1 show that the total transportation costs, travel times and travel distances of shipments in Scenario 1 are generally lower than in Scenario 2, as is the ratio of delay volume to total shipment volume (calculated based on the indifferent interval of arrival time for each shipment). As expected, these results indicate that the simulated freight movements are better organized when real time information is provided, as decision makers are well informed of, and thus can quickly respond to, the changing traffic conditions. The route patterns under both scenarios are shown in Figure 2. From this figure, we can see that the routes selected in Scenario 1 are much more concentrated into a set of links of comparatively less transportation cost than in Scenario 2. In this example, then, real-time traffic information has a significant effect on changing the incidence of the trucks simulated on the regional highway network. However, from the experiment, we also notice that real-time information does not always lead to superior trip planning (see the shaded row of Shipment 7 in Table 1) due to the overestimation of the duration or severity of the incident by the decision-maker in this case.

3.2 Case 1: The Performance Comparisons between the Case of Highly Time-Sensitive Freight and the Base Case Providing Real-Time Information

In this case, we consider the behavior of freight with different delivery time requirements, in particular the behavior of highly time-sensitive freight. Such freight requires fast delivery and reliable transportation, and therefore reducing travel time and travel time variance would be the dominant objectives when routing a trip. Based on these requirements, an experiment was conducted on the same nine shipments used in the base case to study the behavior of this sort of freight. By increasing the weights of travel time and time variance in the cost function to be much larger than those used in the base case, the simulation results shown in Figure 3 were obtained.

The delay time shown in Figure 3 refers to the difference between the actual arrival time and the expected arrival time. These comparisons show that the highly time-sensitive versions of the nine shipments are simulated

Table 1: Comparison of Simulation Results Providing Real-Time Information or Not

Shipment			**Total Cost**		**Travel Time**		**Travel Distance**	
No.	Origin	Destination	Real-Time Scenario	Non-Real-Time Scenario	Real-Time Scenario	Non-Real-Time Scenario	Real-Time Scenario	Non-Real-Time Scenario
1	Middlesex, CT	Barnstable, MA	144.01	150.95	431	462	297.24	299.31
2	Middlesex, CT	Plymouth, MA	226.99	311.43	686	1094	473.94	467.03
3	Middlesex, CT	Worcester, MA	82.84	83.10	230	231	172.69	173.03
4	Middlesex, CT	Hampden, MA	52.14	52.18	152	152	101.22	101.35
5	Greene, NY	Worcester, MA	111.62	112.53	326	330	292.09	293.14
6	Greene, NY	Hampden, MA	172.24	173.38	562	568	363.45	363.45
7	Hamilton, NY	Worcester, MA	210.07	206.98	673	655	452.80	454.70
8	York, ME	Plymouth, MA	95.15	95.60	330	332	228.14	228.73
9	York, ME	Essex, MA	102.98	103.02	312	314	259.03	257.63

Delay Ratio: Real-Time Scenario: 0; Non-Real-Time Scenario: 9.4%.

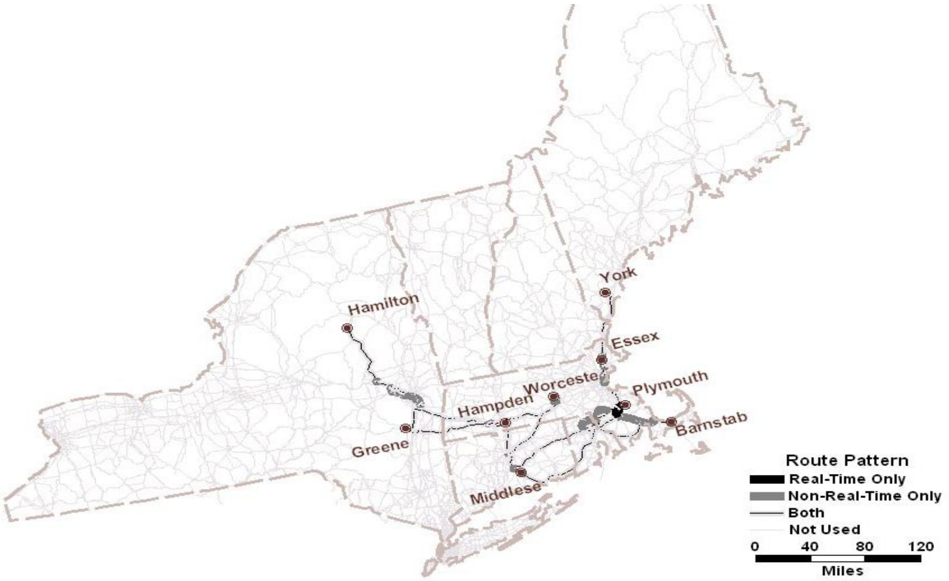
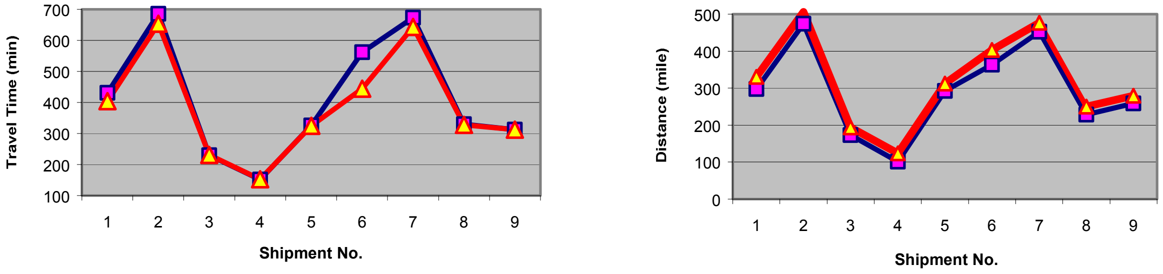
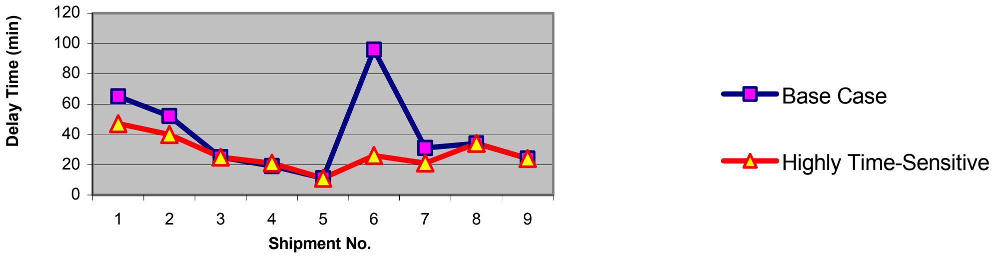


Figure 2: Route Patterns of Simulated Shipments



(a) Comparison of Travel Time

(b) Comparison of Travel Distance



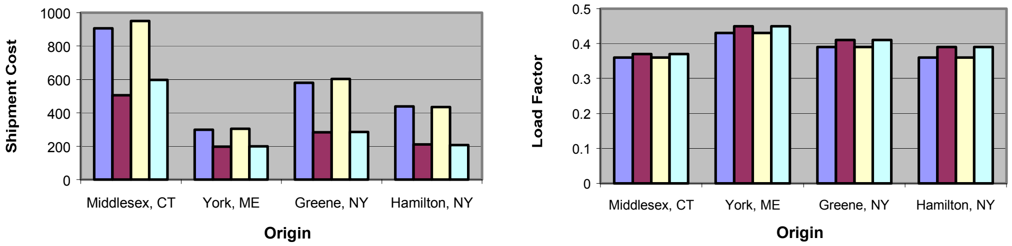
(c) Comparison of Delay Time

Figure 3: Comparisons of Performances Between Different Delivery Time Requirements

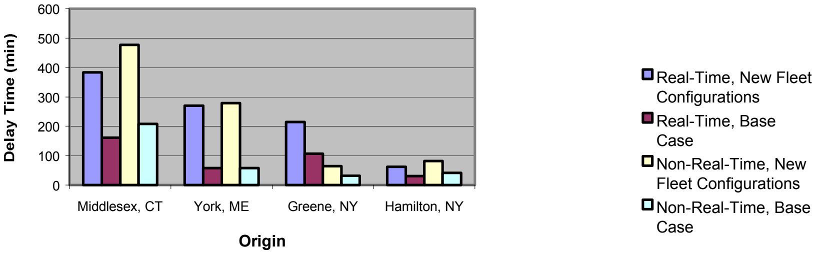
along more reliable routes with lower travel time and variance at the expense of longer travel distance. As a result, the delay time of highly time-sensitive freight is much smaller than in the base case.

3.3 Case 2: The Performance Comparisons between Different Configurations of Vehicle Fleets

Fleet configuration is a major issue in the freight industry. The types and quantities of vehicles in a fleet mainly depend on the type(s) of goods to be transported, and directly influence the operational performance in the corresponding origin. In the experiment, four fleets which correspond to the four origins are involved. In the base case, the fleet in each origin is heterogeneous. This case is compared with a new case in which fleet size remains the same but all vehicles in the fleet are now single-unit trucks. These are trucks of the smallest capacity among the trucks included in the base case fleet configuration. As a result there is less aggregate system capacity available to move goods than in the base case. The simulation results comparing these two cases are shown in Figure 4.



(a) Comparison of Total Cost **(b) Comparison of Load Factors**



(c) Comparison of Delay Time

Figure 4: Comparisons of Performances Between Different Fleet Configurations

From Figure 4, we can see that the total cost and the delay time for the new, small trucks only configuration is much higher than for the base case, and that the load factor of this new configuration is lower than in the base case, with or without real-time information being provided. Significant delay occurs due to a less easily orchestrated match-up between quantity of goods to be moved and vehicle capacity. Therefore, total cost and delay time in the new configuration case increase sharply. A decrease of load factor also occurs, a result of incompatibility between truck size and shipment size. In practice the determination of fleet configuration is an even more complex business, especially when the demand for goods deliveries changes frequently over time. DyFTS is being developed to be able to test the efficiency of specific fleet configurations given the dynamics of this demand.

4 CONCLUSION

In this paper a dynamic freight traffic simulation system was introduced. A key feature of the approach described in this paper is its potential for evaluating the impact of information technologies on the over-the-road movement of freight shipments. The constructed simulation system is becoming a powerful tool for analyzing the operational characteristics of freight movements over a detailed regional transportation network under various decision-making strategies. DyFTS is designed as a highly adaptable system that can be easily embedded into a more comprehensive transportation simulation model. The resulting system can then provide a better, more in-depth understanding of freight movements on the physical transportation network.

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REFERENCES

Cohen, H., and F. Southworth. 1999. On the measurement and valuation of travel time variability due to incidents on freeways. *Journal of Transportation and Statistics* 2(2): 23-132.

Federal Highway Administration. 2003. Dynamic Traffic Assignment Project. Available online via <`www.dynamictrafficassignment.org`>.

Hu, T., and H. S. Mahmassani. 1997. Day-to-day evolution of network flows under real-time information and reactive signal control. *Transportation Research C* 5(1): 51-69.

Loui, R. P. 1983. Optimal paths in graphs with stochastic or multidimensional weights. *Communications of the ACM* 26: 670-676.

Madanat, S. M., M. J. Cassidy, H. Teng, and P. Liu. 1996. Decision-making system for freeway incident response using sequential hypothesis testing methods. *Transportation Research Record* 1554: 228-235.

Mahmassani, H.S., and Y. Liu. 1999. Dynamics of commuting decision behavior under advanced traveler information systems. *Transportation Research C* 7: 91-107.

Southworth, F., and B. E. Peterson. 2001. Intermodal and international freight network modeling. *Transportation Research C* 8: 147-166.

Srinivasan, K. K., and H. S. Mahmassani. 1999. Role of congestion and information in trip-makers' dynamic decision processes experimental investigation. *Transportation Research Record* 1676: 44-52.

Xu, J., K. L. Hancock, and F. Southworth. 2003. Simulation of regional freight movement on the TTMNet: Trade & Transportation Multi-Networks (Paper No. 03-2576). *82nd Transportation Research Board Annual Meeting CD-ROM.*

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