

Synergy Of Incident Management And Real-Time Technology: The Next Step In The Evolution Of Supply Chain Management

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ABSTRACT

Over the last two decades, the culture of the supply chain environment has transformed from one of mass production and distribution to one centered on pull-based demand sensing and response. This transformation, in turn, has necessitated the use of more efficient supply chain operations. One of the cornerstones of efficient supply chain operations is just-in-time (JIT) delivery and inventory reduction, both in-transit and in-facility (Anderson et al 2003, Simchi-Levi et al 2000). The goal of JIT, a sub-part of a larger concept referred to as time-critical logistics (TCL), is to facilitate the delivery of materials only as they are required. This practice, in turn, leads to improved efficiency by reducing inventory costs and idled capacity. In addition, JIT provides increased customer orientation and responsiveness; two very critical elements in an environment of intense competition and rising fuel prices. A vital part of JIT is the routing and scheduling of shipments. Therefore, in order to effectively manage JIT, accurate predictions of routes and travel times are essential. (Miller et al 1999).¹ The JIT approach has dramatically increased the importance of reliability and efficiency throughout supply chain operations, in such areas as the sourcing of goods, transportation, manufacturing, and distribution.

Keywords: Supply Chain, Transportation, Incident Management, Traffic Congestion

BACKGROUND OF PROBLEM

While reliability and efficiency in supply and manufacturing processes can be ensured through best practices, ensuring the reliability of logistics operations is more complicated due to inefficiencies in the transportation network (TTI 2005, FHWA Report).² These inefficiencies are due in large measure, around 50% as reported by AASHTO³, to the occurrence of incidents, or non-recurring events, rather than heavy traffic volume. Incidents can materialize in a variety of forms: accidents, vehicle breakdowns, chemical spills, police investigation closures, downed power lines, and even alterations in the shipment's final destination. It is important to remember that heavy traffic volume itself is not an incident. Thus any delays resulting from an incident are added to whatever delays may already be in place due to heavy traffic volume.

The more systemic, underlying causes of incidents in the transportation network take a variety of forms: population and job growth in urban/metropolitan areas, a more exhaustive use of automobiles, the desire to reduce

¹ 32nd Hawaii International Conference on System Sciences "GIS-Based Dynamic Traffic Congestion Modeling to Support Time-Critical Logistics" 1999

² Texas Transportation Inst.: 2005 Urban Mobility report. FHWA report "An Initial Assessment of Freight Bottlenecks on Highways"

³ The American Association of State Highway and Transportation Officials (www.aashto.org)

densely populated neighborhoods, a preference for less crowded working environments, and an all around consumer desire for private vehicles. According to a paper from the 32nd Hawaii International Conference on System Sciences⁴, there are several important factors that must be taken into account. First, traffic congestion patterns are spatially complex. As a result, traffic congestion is often dispersed enough so that it is difficult to avoid regardless of the route taken. Second, the peak periods previously associated with the morning and evening “rush” are declining. This decline stems from a national movement from manufacturing based jobs to more service oriented jobs. These service oriented jobs cover a broader geographic area and consume more hours in a day. Third, non-work related travel is increasing at a higher rate than work related travel. Finally, congestion is dynamic in nature. It can occur at a single location and spread to nearby parts of the transportation network. In addition, because transportation networks often operate close to capacity, they are especially susceptible to congestion resulting from incidents. Congestion must be dealt with throughout much of any given workday; it is no longer feasible to simply avoid problem areas during certain periods in order to arrive at a desired destination on time.

These inefficiencies are a serious problem because they have a “direct” effect on the economics associated with logistical operations. In addition to resultant increases in fuel and driver costs, they significantly affect supply chain operations through missed deliveries, idled capacity and labor, and increased schedule nervousness throughout the entire supply chain (McKinnon 2004, Rao et al 1991). For example⁵, when assembly line production in the automotive industry is brought to a halt due to delayed arrival of a necessary shipment, the amount of money lost can range anywhere from 10 to 100 times the revenue earned by the trucking company in delivering that one shipment. The enormity of all these costs, estimated at \$200 billion a year, and the critical need to mitigate the effects of traffic congestion, is presented in DOT’s 2006 Report.⁶ However, this report also states these disruption costs are neither measured nor accounted for, despite the fact that they far exceed direct transportation cost inefficiencies.

A grasp of this problem’s scope is reflected in the DOT’s strategic RD&T plan (U.S. DOT: Strategic RD&T Plan 2006-2010), which identifies the following five strategic goals:

- Reduce urban and suburban traffic congestion, freight gateway congestion, and aviation system congestion
- Extend the life of the existing transportation system and improve the durability of the infrastructure
- Conduct and sponsor research to advance the use of next generation technologies and to make effective use of combinations of modes in moving people and goods
- Improve the planning, operation, and management of surface transportation and aviation services and assets
- Improve transportation services for underserved areas and populations

LITERATURE

Past work in this area can be drawn from several different research topics. In providing various methods for estimation of incident delays, Golob et al (1987) and Ozbay and Kachroo (1999) recommended probabilistic distributions, while Giuliano (1989) and Garib et al (1997) applied linear regression models to incident data. Jones et al (1991) proposed a conditional probability model with hazard functions, which Nam and Mannering extended (2000) using industrial engineering and biometrics hazard functions to estimate incident duration. With respect to the reliability of travel times, Noland and Polak (2002) reviewed the theory and empirical results of studies attempting to measure behavioral responses to changes in travel time variability. Cohen and Southworth (1999) provided a model to estimate variance and mean of delay resulting from incidents on freeways and review valuation methods.

With respect to dynamic routing algorithms, a number of studies have tackled the routing problem with stochastic and non-stationary travel times (Hall 1986, Miller-Hooks and Mahmassani 2000 and 2003, Bander and White 2002). Studies that consider real-time information for dynamic routing are relatively recent (Psaraftis and

⁴ GIS-Based Dynamic Traffic Congestion Modeling to Support Time-Critical Logistics” 1999

⁵ “A Heuristic Search Approach for a Nonstationary Stochastic Shortest Path Problem with Terminal Cost”

⁶ DOT’s 2006 report, “National Strategy to Reduce Congestion on America’s Transportation Network” in May 2006

Tsitsiklis 1993, Polychronopoulos and Tsitsiklis 1996, Azaron and Kianfar 2003, Fu 2001, Waller and Ziliaskopoulos 2002, Gao and Chabini 2006, Kim et al. 2005, Thomas and White 2007). However, these studies lack the joint consideration of recurring and non-recurring congestion. Moreover, none of these studies have undertaken a comprehensive analysis on the performance of alternative heuristics, computational performance comparisons between exact and heuristic methods, or the impact of approximations on performance and quality. In addition, the incident models in these few studies lack practical aspects, such as network propagation. Finally, with respect to the effect of logistics costs, McKinnon (2004) discussed the impact of delivery unreliability on supply chain and logistics costs in the case of the United Kingdom's foods industry. For JIT replenishment systems, Rao and Grenoble (1991) proposed a model and suggested various alternatives for improving logistics performance influenced by traffic congestion.

SOLUTIONS

An assortment of strategies have been proposed and implemented for reducing the congestion leading to inefficient use of the transportation system. One strategy is investment in new capacity. However, although this may appear to be an effective means of reducing congestion, such a strategy has several flaws. It is by no means conjecture that the costs associated with expanding the capacity of all major corridors in a state's transportation system are probably not within a state's budget. Thus, improvements are made to selective problem areas deemed to be the most critical. In order to facilitate construction, traffic must be diverted, at least to some degree, around the selected areas for the duration of the project. If the selected improvement zone is a major roadway or intersection, this re-routing could divert traffic along roads with even less capacity than the one being altered. Also, given the frequency with which the proposed construction area is utilized before the construction, it may be difficult to perform all of the necessary construction at once. The closing of miles and miles of a major interstate within a major metropolitan area could prove to have crippling economic effects. The alternative, shutting portions of the road down one at a time, will only further prolong delays associated with the construction period.

Even if the capacity of a major corridor can be expanded at minimal cost and inconvenience, the reductions obtained by the reconstructed corridor may become obsolete after only a few years. Investment in new capacity can, at best, be viewed as a temporary fix to a problem that may come back even stronger the next time it arises. Instead of adding new capacity in order to reduce congestion, a better means of reaching this goal is to find a way to use the existing system in a more efficient manner.

According to AASHTO⁷, there are numerous examples of strategies that attempt to reduce congestion by using existing transportation systems in a more efficient manner. For example, several states have attempted to use pricing strategies as a means of alleviating congestion. One such example is the use of high-occupancy toll (HOT) lanes. The goal of HOT lanes is to allow for more freely moving conditions by using toll prices to manage traffic flow. Since 1993, California, Colorado, Minnesota, and Texas have all implemented HOT lanes to help ease congestion. Another congestion reduction strategy is the use of 511 systems, which allow travelers to call in and obtain up-to-date traffic information. The state of Florida has continuously improved its 511 system, allowing users to pre-program up to 11 frequently traveled routes. This, in turn, allows for instant access to updates over the phone. A 2006 poll by the FDOT revealed that one-third of people who use the 511 service call ahead before beginning a trip, and two-thirds use it after encountering a problem on the road. A third example is the use of access management policies in order to reduce congestion. Proper access management for a major corridor is vital when significant growth is expected. Several state transportation agencies are working in conjunction with local communities to develop strategies to reduce congestion in these corridors. These strategies consider elements such as no-access/access-control lines, parcel-to-parcel access, driveway spacing standards, and frontage roads. Other strategies include multimodal transportation corridor investment, integrated corridor management strategies and coordinated incident management.

⁷ The American Association of State Highway and Transportation Officials (www.aashto.org)

Although these solutions undoubtedly have some value, they still appear to fall a bit short. In the context of non-recurring delays, the necessary requirements for widespread utilization of information streams from any system are: 1) incident information timeliness, 2) quality of information (includes speed in addition to traffic volume), and 3) coverage (includes all roadways that see dense freight transportation). No existing system meets all three requirements, which could explain the main reason for low adoption of this technology. A more advanced communication system, addressing all three aspects of incident information fidelity, would be strongly embraced by supply chain and logistics service providers. An alternative approach is to reduce the impact of these low probability-high impact delays by informing the drivers with near real-time and en-route up-to-date road congestion information.

In developing routing optimization models and algorithms, the emphasis should be placed on dynamic models and algorithms, which not only account for real-time traffic information (recurring, and nonrecurring congestion such as incidents) from ITS sources, but also anticipate changes in traffic conditions. These dynamic models are compared with their static model counterparts under different scenarios. Given a scenario (i.e., load, incident state and incident fidelity), static models use approximate (stationary) probability distributions of congestion levels in the road segments. Accordingly, optimization methods are classical shortest-path techniques with random travel times. Dynamic models account for non-stationary probability distributions and develop exact and heuristic solution techniques. Markov decision processes (MDPs) and variants are the candidates for dynamic models. These dynamic models result in large formulation instances and thus require significant computational resources. On the other hand, static models are manageable in their computational complexity. The objective with these two models is to find the optimal detail level, such that a quality solution can be obtained and submitted to the driver through ATIS within time constraints. Both models (static and dynamic) have been simulated over different network scenarios to account for validation.

Using the current algorithms that have been developed, various assumptions will be relaxed in order to achieve the following goals:

- Extend the dynamic routing algorithms to account for cycles within the network, incidents on distant links, and travel within larger networks
- Methods for estimation of travel time (or cost) variance besides the expected travel time (or cost)
- Heuristics for computational/memory efficiency
- Develop computationally efficient yet effective shockwave models that account for incident related traffic shockwaves propagating through nodes

The majority of initial efforts have focused on developing preliminary dynamic models and algorithms that can account for real-time congestion and incident information. By relaxing a majority of assumptions (e.g., allowing traffic conditions on adjacent links to be correlated instead of treating them as independent) new insights can be gained. Subsequently, the goals are to improve the accuracy of our dynamic routing models, develop representative incident models, and speed up our solution algorithms. Specifically, the dynamic routing models and algorithms will be extended to account for cyclic networks, networks with waiting at nodes, one-to-many distribution with constraints (e.g., delivery time windows), and correlated congestion states of adjacent links.

In addition, dynamic routing models and algorithms with objectives other than expected cost (time) minimization will be developed. One such alternative objective is travel time reliability (or variance), which will be modeled either as a performance measure or a service level requirement. Even though the current models account for dynamic incident information, this is achieved through a simple incident model. More sophisticated incident models will be developed that capture the effect of congestion shockwaves propagating through the network. The current state of knowledge on shockwaves is limited to single links, and the goal is to model this shockwave propagation throughout general networks. Accordingly, these shockwave models must not only be computationally efficient, but also effective in accounting for incident delays. New and improved existing exact and heuristic solution algorithms to achieve efficiency in computational time and memory requirements will be developed concurrently to the model development and refinement efforts.

The ultimate goal is to analyze the costs and benefits within the supply chain associated with sharing near real-time road network information and navigation with drivers (freight drivers in particular) and dispatchers. Using routing models, static and dynamic algorithms, and simulation studies of road networks, measurements of both the direct and the indirect benefits of communicating non-recurring information will be gathered. In order to account for system level variability, these models will be simulated with different road network “scenarios”: different *loads* (e.g. various times/days), *incident states* (i.e. severity; duration and reduction in capacity), and dissemination *information fidelity* (incident maturity, position of freight vehicle, traffic speed). Various distribution strategies, such as “one-to-one” and “one-to-many”, will be considered.

The benefits of communicating non-recurring incident information to drivers using a “one-to-many” strategy will be better, in general, due to more freedom within the routes. The simulation models will use internal optimization models. More specifically, given a particular network scenario (load, incident, information fidelity), two cases will be compared: the first being where the vehicle routing remains constant and the second being where the latest road network information is provided to the driver and an optimal rerouting decision is made.

In order to optimize the routing decision upon receipt of information, the developed models and algorithms will be compared with standard state-of-the art routing/optimization algorithms. Thus, the framework includes two main modules: a scenario generator and a dynamic routing optimization module. The output of simulation models is the expected delay under different scenarios. Clearly, there will be minimal benefit in avoiding congestion for some scenarios, due to the location of the vehicle and timing of the incident communication. Upon each simulation run, a comparison of the delivery time of original routing and dynamic response routing will be made. Comparative results will then be classified according to their scenario settings in a simulation results database: road network structure, load, incident state, information fidelity, and delivery strategy. Since carriers vary among each other in terms of their coverage, the type of road network used, delivery characteristics, and customer characteristics, the post-simulation analysis will need to account for such variation.

CONCLUSION

The transformation that has taken place within the supply chain environment requires the use of more efficient supply chain operations. JIT is a way to achieve this efficiency, but achieving reliability in logistical operations is complicated by factors posed by inefficiencies in the transportation network. Although a variety of strategies have been proposed in an effort to alleviate the problems posed by these inefficiencies, the one strategy that will likely yield the best results is the utilization of information streams to provide live, up-to-date information on traffic conditions. However, strategies focusing on non-recurring delays do not meet each of the three necessary requirements for widespread utilization of information streams. A more advanced communication system, addressing all three requirements, would be a useful tool for supply chain and logistics service providers.

The ultimate goal of this research is to develop dynamic routing algorithms interfaced with real-time commercial GIS software that supports constraints (e.g., user request to avoid local roads) and trips with multiple-legs (e.g., to support milk-run shipments). The validation studies will involve extensive testing of the models. A key part of the validation will be to study the impact of these dynamic routing algorithms on the performance of Just-in-Time (JIT) deliveries, using data and statistics regarding freight delivery patterns/performance/costs between the facilities and the key JIT suppliers. This has led to other research questions:

With respect to the timeliness requirement of widespread utilization of information streams, will a higher frequency of information dissemination help to maximize the optimality of any routing decision? For example, re-evaluation of a link deemed optimal as a vehicle began traversing upon it, but subsequently deemed suboptimal, may allow for re-routing off that now inefficient link depending upon the availability of access roads.

Under the quality of information requirement, the question emerges of whether the information supplied will take into account the volume of traffic likely to utilize the advised alternate route, the feasibility of u-turns, the utility of changing course as opposed to “waiting it out,” or any possible constraints on alternate routes, such as weight/axle limits.

AUTHOR INFORMATION

Dr. Gregory Ulferts is a Professor of Decision and Systems Sciences in the College of Business Administration. His scholarly activities have included research and publication on various topics related to management information systems, financial management, decision sciences, small business administration, and international business. Dr. Ulferts has served as a consultant in business and government in areas such as strategic and technology planning, operations and procurement management, analysis and design of systems, and business development. Since 1997, he has worked with the Regional Chamber of Commerce, American Society of Employers, and National Association of Manufacturers. He is a certified Cost Estimator/Analyst and has worked on U.S. Department of Labor, U.S. Department of Commerce and U.S. Department of Transportation projects.

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