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Threat Reduction in Logistics via Real-Time Vehicle Routing System Using Wireless Technologies

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Abstract

In present scenario many technological advances have led to renewed interest on dynamic Vehicle Routing (VR) problems. The execution of vehicle routing is critical in successful supply chain and logistics. The coming out of technologies and information systems allowing for flawless wireless and wireless connectivity between delivery vehicles and distribution facilities is paving the way for innovative approaches to real-time VR and distribution management for a different glass models. This paper examines avenues for building upon recent trends in VRrelated research towards an integrated approach to real-time distribution management for glass manufacturing industry. A review of the advances to-date in both fields, i.e. the relevant research in the VR problem and the advances in wireless technologies, forms the basis of this investigation. Further to setting requirements, we propose system architecture for urban and semi-urban distribution and real-time event driven vehicle management.

Key words: Vehicle routing, Real-time scheduling, Decision support systems, Wireless technologies

1. Introduction

Planning and execution are the two major categories of supply chain management processes. While Supply Chain Planning (SCP) embraces the processes related to forecasting materials requirements, planning for production and distribution etc, Supply Chain Execution (SCE) focus on the actual implementation of the supply chain plan, comprising processes such as production and stock control, ware house management, transportation, and delivery. SCP has attracted significant attention over the last two decades, due to its critical impact on customer service, cost effectiveness, and, thus, competitiveness in increasingly demanding global markets. As an outgrowth of the research advances in this area, a number of technology-enabled systems have also appeared to assist in SCP operations including Enterprise Resource Planning (ERP), Manufacturing Resource Planning-II, Materials Resource Planning (MRP) applications and integrated SCP information systems. SCE has equally received less attention at least in real-time decision making and threat management is concerned. While processes such as stock control and warehouse management have been thoroughly investigated and supported by applications such as Warehouse Management Systems (WMS), improvement opportunities still lie in the area of delivery management (Ghiani et al., 2003). In this area, most extant work has focused on optimally allocating vehicles to known delivery demand under a precedence assumed conditions. Equally limited research has to date been dedicated to the real-time management of vehicles during the actual execution of the distribution schedule in order to respond to unexpected events that often occur and may deteriorate the effectiveness of the predefined and static routing decisions. Such events, that create a dynamically changing problem state, include traffic conditions, vehicle-related incidents, market-triggered events and so on. This latter area is the focus of this paper, which investigates how technological advances in the fields of wireless and wireless computing can be employed towards an integrated architecture for wireless-enabled real-time distribution management applications. The paper reviews special bibliography in vehicle routing in light of recent technological developments and proposes a generic architecture for wireless real-time Decision Support Systems (DSS) for urban and semi-urban distribution of different glass models.

2. The urban and semi-urban sharing environment.

Delivery is a key logistics activity and contributes, on average, the highest portion to the total logistics-related costs. Distributors face multifaceted problems of formative the finest number, capacity, location of facilities serving more than one customer and also finding the optimal set of vehicle and routes. The glass manufacturer may discriminate at least two ways for sharing goods in an urban and semi-urban area either on standard deliveries or direct company sales. While both cases use a typical delivery network with M warehouses that deliver to N customers through a fleet of F vehicles, they differ in the way they handle demand. The performance of either urban or semi-urban allocation model may get worse significantly due to a number of factors. In the case of standard deliveries, such events may include traffic congestion, truck breakdowns, ramp overload at points of delivery, unforeseen reverse logistics requests, and others (Ghiani et al., 2003). This situation may become even more complex in the case of direct sales, where inefficiencies usually stalk from the inherent demand/route uncertainty of the model, raising complex requirements for real-time decision making. For instance, due to unexpected high demand if a vehicle has delivered of its entire inventory in the first few points of sales, it may be beneficial for another vehicle be re-routed in order to accommodate the increased sales needs in the first vehicle's region. So it is clear that, while an efficient primary routing chart is necessary, it is by no means sufficient to minimize threat in high performance distribution systems. Preliminary routing plans need to be complemented by the ability to make and implement sophisticated decisions in real-time in order to respond effectively to unforeseen events. We contend that this requirement may be facilitated by innovative technology-augmented approaches combining inter vehicle wireless communication, rear-end wireless connectivity with the distribution center, and real-time decision support.

3. Relevant literature on VRP and VRS

3.1. Parameters of the real-time VRP

In the region of goods transportation many problems by fleets can be modeled, to a certain extent, within the vehicle routing problem (VRP) framework which is shown in the Figure 1.

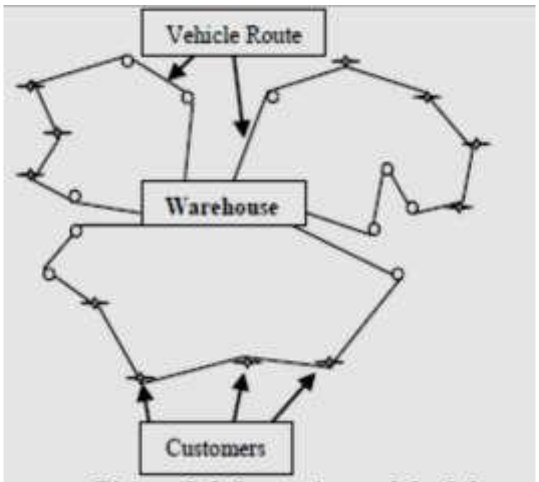

Figure 1 Schematic model of the typical vehicle routing problem

The aim of the typical VRP is the design of routes for delivery vehicles that operate from a single warehouse and supply a set of customers at identified locations, with acknowledged demand of required glass models. Vehicle routes are usually designed to minimize the total distance traveled present the formulation of the typical VRP. In an effort to model and address important practical issues, the fundamental vehicle routing problem has been extended in a number of aspects. Certainly, one can differentiate no less than seven parameters of critical importance that raise considerable challenges in vehicle routing problem related research and are all closely related to the real-time vehicle management problem:

(1) Deterministic vs. stochastic supply / demand: The deterministic VRP assumes that demand/supply is known a priori, while the stochastic VRP encompasses uncertainty in demand and/or supply levels.

(2) Stages: While the single-stage VRP either delivery or pickup is primarily concerned with the establishment of outbound delivery routes, the double-stage VRP considers both inbound and outbound distribution. The latter is a salient feature of real-time distribution, since reverse logistics may necessitate adjustments to the original schedule depending on the truckload and its capacity.

(3) Truck size and capacity: We can differentiate between cases of single vehicle and multiple vehicles. As the number of vehicles in the delivery fleet is increased, the problem size, as well as the computational complexity, increases accordingly. It is clear, that the multiple vehicle case is appropriate in the real-time vehicle management problem, since many contingency measures involve the cooperation between vehicles through appropriate inter-vehicle communication infrastructure. There exist formulations for both the capacitated VRP (CVRP) and the incapacitated VRP depending on whether vehicle capacities are considered. The CVRP, as presented for example in Toth and Vigo (2002a), is perhaps among the most widely researched variations of the problem.

(4) Planning scope: The static VRP takes into consideration a single planning period while the dynamic VRP considers optimal solutions in multiple periods. In this case the initial schedule can be adjusted, according to the current needs for distribution.

(5) Time windows: A classical variation of the VRP refers to the consideration of time windows, outside which deliveries cannot be accepted. Time windows can either be "hard", when they cannot be violated, or "soft", in which case violations are accepted but penalized. Time windows present one of the most common causes for the need of real-time incident management Ioannou et al (2003).

(6) Objectives and Source of data: The most common vehicle routing problem objective is to minimize the total cost of deliveries. However, additional objectives might be considered, such as Warehouse Vehicle Route

Customers minimizing number of warehouses or maximizing customer satisfaction. Proposed approaches for addressing the VRP are tested either through artificial data set, constructed for this purpose, or through data collected via case studies.

(7) Algorithmic approach: The problem of VRP is an non-deterministic polynomial hard problem and thus cannot be solved to optimality within reasonable time. This fact has prompted the development of heuristics that started to emerge in the 1970s, which still comprise a significant research area. A current example of a meta-heuristic tabu search method for the VRP has been presented by Ho and Haugland (2004). Exact solutions have also been developed, however they can only be applied to vehicle routing problems of limited complexity (Reimann et al., 2003). In fact, exact algorithms are challenged by problems with more than 60-80 customers (Toth and Vigo, 2002b).

3.2. Real-time VR and VRS

A further area for research is dynamic planning, especially dynamic re-scheduling and re-routing of vehicles, the relevance of which, has increased due to the appearance of technologies enabling real-time, high-bandwidth information exchange between fleet vehicles and its headquarters. Real-time vehicle management depends strongly on significant information exchange supported by appropriate information system infrastructure. Tarantilis and Kiranoudis (2002), present spatial DSS and included typical elements i.e. a database, an algorithmic engine and a user interface to coordinate and disseminate tasks and related information for solving the VRP using a met heuristic method. Its architecture integrates a geographic information system (GIS) system, a relational database management system (RDBMS), and special software tools. Zografos et al. (2002) developed a DSS to address Incident Response Logistics (IRL). The system provides functionalities including districting, dispatching of response units, routing of response units, and on-scene management. Gayialis and Tatsiopoulos (2004) developed a DSS that combines a SCM application with a GIS and an ERP system to support planning and management of oil delivery trucks. These systems present different approaches for addressing specific instances of real-time vehicle routing. Such an analysis yields important findings regarding the type of algorithmic approaches that fashion to support real-time vehicle routing, as well can be realistically implemented in a cost effective as regarding the technologies that can support these algorithmic approaches.

4. A generic architecture for real-time VRS

4.1. Real-time vehicle management framework

Many solutions approach to the VRP are in practice implemented in a centralized computer resource normally at headquarters, producing a daily plan to be provided to the vehicles before the beginning of the distribution execution. Some of these approaches have been implemented in commercial systems that are successfully used by numerous transportation, logistics, and manufacturing companies over the last 20 years. These systems have not, however, been designed to address the case in which the execution of delivery cannot follow the plan as prescribed, due to some unpredicted event. When there is a need for real-time intervention, it may be necessary to re-compute the plan using new input data.

Thus, re-planning based on classical VRP solution methods may not be a realistic option. In the absence of algorithms capable of "isolating" the part of the VRP affected by the unexpected event in order to minimize the disturbance and urban to the overall schedule, interventions are typically performed manually for example, through voice communication between drivers and the logistics manager and the quality of decisions taken is naturally affected.

The need for enhancing existing methods or developing novel approaches becomes clear in view of the recent advancements in wireless and positioning technologies. Using such technologies, information about unpredicted events may be transmitted when they occur directly from the affected truck(s) through a wireless network to headquarters and/or other parts of the fleet. Given an efficient re-planning algorithm, appropriate and implementable plan modifications may be transmitted back to the fleet in a timely fashion to respond effectively to the new system state. The real-time vehicle routing problem is depicted schematically in Figure 2, using control system formalism. The important issues regarding this problem can be classified in two groups: system issues and decision-making issues.

CONTROL EXECUTION

FEEDBACK

The system issues are as follows.

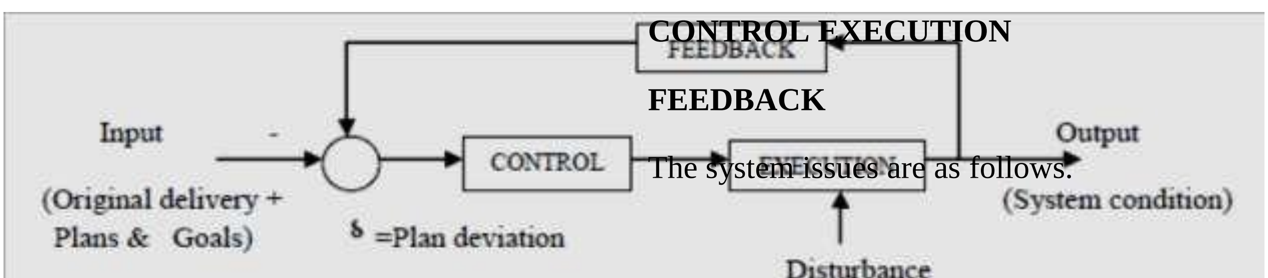

Figure 2 Schematic representation of the real-time vehicle management problem

System's state observation: It means that the selections of the parameters are to be monitored regularly, such as truck position, truck speed, truck inventory, etc. as they will trigger intervention if needed. It is noted that interventions may lead to system "nervousness"; thus, the cost of intervention should be balanced against expected benefits.

Intervention types:

Global re-planning may lead to near optimal solutions; however it can also cause significant disturbances for urban and semi-urban to the original routing schedule. Moreover, global re planning imposes heavy communication overhead and additional costs to the system because all trucks need to report their current status to the headquarters in order to provide new input data for the VRP. Finally, global re-planning is also heavy computing workload for the central system. On the other hand, local plan adjustments may provide more cost-effective solutions without unnecessarily disturbing the overall initial plan. This benefit comes of course at the cost of needing to design more complex algorithms that decompose the VRP efficiently and solve only the affected part of the initial problem.

Objective of the system:

Objectives to be considered may include: minimize the deviation from the original plan, minimize the cost of non-conformance, minimize threat, and others. Important decision-making issues include modeling of the real time re-planning problem, and development of appropriate solution methods. A classical way to reduce complication is by using a hierarchical approach, whereby, a complex monolithic problem is decomposed, or disaggregated, to multiple, simpler problems that can be solved independently.

An interesting, relevant approach for solving the VRP has been proposed by Reimann et al.(2003), who presented an algorithm that builds on the savings-based ant system. In addition to the way of decomposing the problem, an appropriate enhancement of this approach concerns the way the computation of the sub-problems proceeds.

4.2. System execution issues

The system presented in Figure 2 can be realized through the use of wireless technologies, real-time decision-making algorithms and back-office automated processing. In addition to providing the appropriate directions to the drivers of the truck, the customer base may be kept informed, in regard to changes in the initial schedule, therefore improving service quality and customer relations of the company.

The proposed system architecture is shown in Figure 3. It comprises three major sub-systems. The rear-end system consists of a decision making module to facilitate automated decision making and ERP connectivity. The wireless communication sub-system allows a communication between rear-end & frontend systems. The front-end system enables:

1. A robust user interface

2. Local computations

3. Interaction between the software platform that is installed in the on-board truck computer and the company's Rear-end system.

Rear-end sub-system:

The Rear-end system is a DSS that incorporates algorithms needed for real-time routing, scheduling, and monitoring of the current state of the vehicle, as well as a robust database containing both static of customers, geographical information of the road network, etc as well as dynamic of orders, quantities, time window information, etc data. The Rear-end system also provides ERP connectivity, which is especially useful in direct sales to provide information, such as customer sales history, customer credit, and other decision-critical data.

Table 1 Mobile network access technologies

Type of mobile network	Availability	Max. data rates	Data service provision
Global System for wireless communications (GSM)	Yes	14.4 Kb/s	Circuit-switched
General Packet Radio Service (GPRS)	Yes	172 Kb/s	Packet-switched
Terrestrial Trunked Radio (TETRA)	Ltd	28.8 Kb/s	Packet-switched
Universal Mobile Telecommunications System (UMTS)	Ltd	7.2 Mb/s	Packet-switched

Wireless communication sub-system:

The wireless communication sub-system consists of two parts:

1. The wireless access terrestrial network, which is responsible for the wireless interconnection of the Rear-end system with the front-end on-board devices

2. The positioning system, which is responsible for vehicle tracking. The wireless access terrestrial network can be based on any number of existing or emerging wireless technologies shown in Table 1. In examining the options available to support an integrated distribution system, bandwidth is perhaps the most important issue. The bandwidth requirements depend on the computational model chosen. If vehicle on-board devices support much of the computations, then the demand for bandwidth is different than in the case in which much of the computation is performed at headquarters. In either case, however, the demand for bandwidth is greater when compared to existing applications, such as fleet tracking, graphical representation of real-time information in digital maps, and voice communication. GPRS, TETRA, and UMTS can provide alwayson, packet-switched connectivity and high-speed data rates. GSM is a mature technology; however it cannot support high-data transmission effectively. GPRS combines high data rates, always-on connectivity, mature technology, and has also been used in fleet management systems. As far as TETRA is concerned, it is worth mentioning that it provides much better security than GPRS, as well as it supports point-tomultipoint voice broadcasting. UMTS is an emerging standard and its use cannot be assessed prior to thorough validation testing.

In the positioning system, positional accuracy of less than 100m is deemed acceptable for urban and semi-urban distribution. An analysis of the technologies that can be used for location identification goes beyond the scope of the paper (Zeimpekis, 2003) however Table 2 represents the characteristics of some of the most widely-used technologies today. In the positioning system, positional accuracy of less than 100m is deemed acceptable for urban and semi-urban distribution.

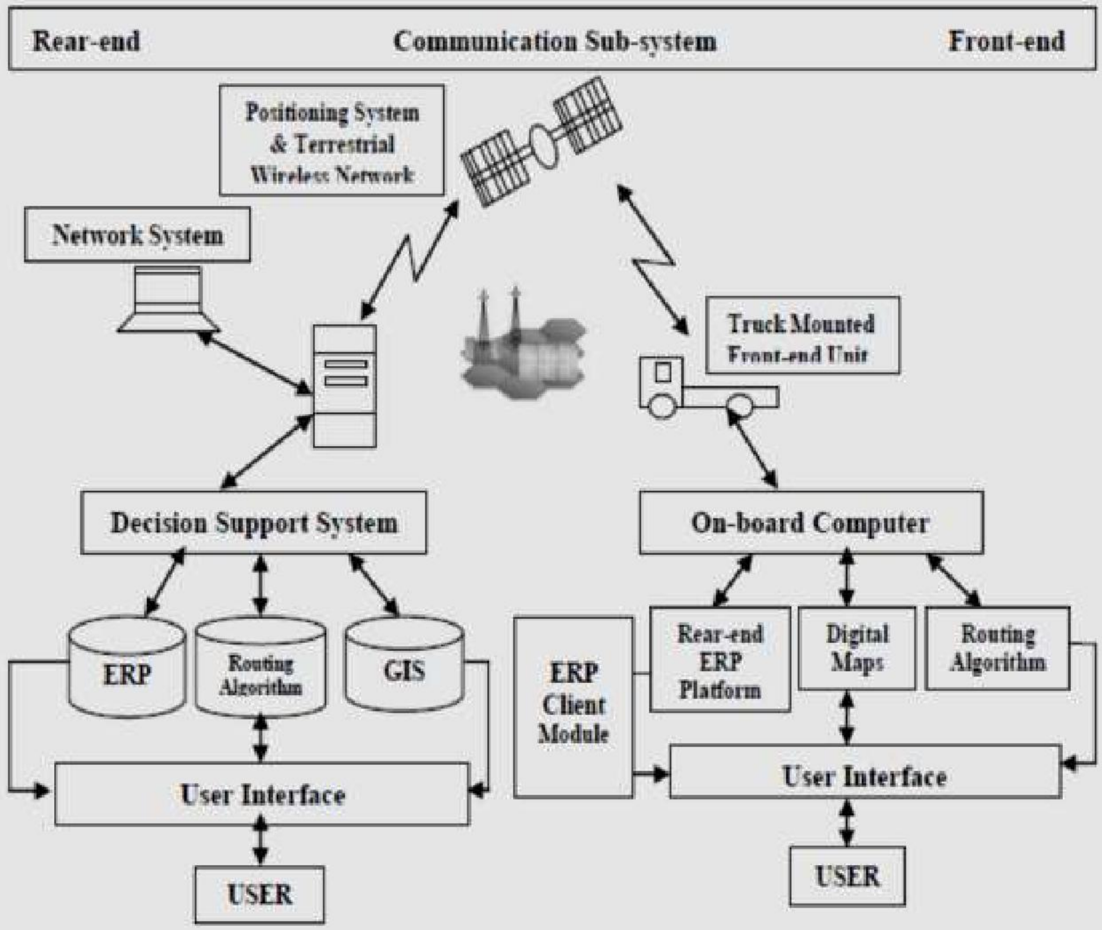

Figure 3 Proposed System of Architecture for Real-Time Vehicle Management

Table 2 Accuracy of positioning methods

Network	Accuracy
Differential GPS	5-50m
Terrestrial beacon	Up to 50m
Global Positioning System (GPS)	100m
Low Earth Orbit (LEO) satellites	1km

An analysis of the technologies that can be used for location identification goes beyond the scope of the paper (Zeimpekis, 2003) however Table 2 represents the characteristics of some of the most widely-used technologies today. GPS appears to be the most preferable solution, since it is a globally available, free-of-charge system. Front-end system: The front-end system generally consists of a wireless device, to which all necessary information is sent from headquarters or from other vehicles, and a tracking system that will be connected to the wireless device for the provision of routing information. The selection of the front-end device is important both from a user interface and from a computational performance perspective. The latter is required, since at least a part of the necessary computations will be performed on-board (e.g. route recomputation, or delivery re-scheduling), especially in those cases that a problem may be solved locally without affecting many other vehicles or routes. Typical wireless devices that can be used on-board include wireless phones, personal digital assistants (PDAs), and tablet PCs. In their present state, wireless phones do not appear capable of coping with the requirements of the applications under consideration. PDAs are already used for specific distribution applications such as rear-end ERP connectivity. On the other hand, tablet PCs seem to combine all features of wireless phones and PDAs and provide superior computational power. In addition, Tablet PCs include high-resolution displays, wireless networking capabilities, and integrated support for peripherals.

5. Conclusions

Real-time vehicle management system is important in supporting supply chain execution, and in minimizing the related logistics threats for glass industry products. It has been demonstrated that a good, earoptimal, distribution plan is necessary but not sufficient for high performance distribution. This needs to be complemented by the ability to make and implement sophisticated decisions in real-time in order to respond effectively to sudden events. In order to develop strong, Decision Support System On-board Computer User Interface Rear-end ERP Platform Digital Wireless Network Rear-end Communication Sub-system Front-end practical approaches to the real-time vehicle management problem, research efforts should focus on three aspects: design of systems, decision support methods, and system implementation.

- In the design of systems, significant issues to be considered include: the systems objectives, the observability of the system's state; balance of intervention costs vs. expected benefits; extend of interventions and other parameters. Due to their heavy dependence on the characteristics of the problem addressed and the algorithmic approach chosen for intervention design of systems cannot be generalized beyond the extent achieved in this paper. Therefore, future research can assess alternative design specifications against real-life case studies of real-time vehicle routing problems.
- In the decision support methods problem complexity and computational time play a significant role in system effectiveness. Hierarchical disintegration seems to be a promising direction, provided that the "goodness" of disintegration is appropriately addressed.
- In the system implementation, it appears that there exist mature technologies to sufficiently address the requirements of the real-time vehicle management system. In terms of the communication subsystem, GPRS and TETRA are appropriate wireless access networks, while GPS technologies meet all the related positioning requirements. All three parameters are discussed above present interesting challenges with major implications to both the VRP-related research and to the technology that will support effective logistics execution in glass manufacturing industry.

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