Dynamic Dispatching and Transport Optimization – Real-World Experience with Perspectives on Pervasive Technology Integration

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Abstract

This paper discusses a technological solution to real-time road transportation optimization using a commercial multi-agent based system, LS/ATN, which has been proven through real-world deployment to reduce transportation costs for both small and large fleets in the full and part load business. Subsequent to describing the real-time optimization approach, we discuss how the platform is currently evolving to accept live data from vehicles in the fleet in order to improve optimization accuracy. A selection of the predominant pervasive technologies available today for enhancing intelligent route optimization is described.

1. Introduction

In today's fast paced, data-intensive and uncertain global markets, road freight transportation is a high-pressure environment. Competition is fierce, margins are slender and coordination can be both distributed and intensely complex. Supply relations are transnational, often global, and goods must reach their destinations faster than ever before as they are now often directly entered into production processes without passing through transitional storage [1].

As a result, many companies are seeking to control costs by enhancing their traditional human-centric dispatching methods with technology capable of intelligent, real-time freight capacity and route optimization [2]. The capacity aspect ensures efficient use of transport capacity while the route aspect ensures that trucks take the most efficient route between order pickups and deliveries. These are tractable, yet complex optimization problems because plans can effectively become obsolete the moment a truck leaves the loading dock due to unforeseen real-world events. It is thus mission-critical to assist human dispatchers with the computational systems to quickly and accurately re-plan capacity and routing. The Living Systems® Adaptive Transportation Networks (LS/ATN) software, see Figure 1, developed by Whitestein Technologies in close collaboration with worldwide logistics providers (e.g. DHL), is a concrete example of how automatic, real-time optimization and execution capabilities lead to reductions in transportation operating costs while improving service quality to the customer [3].

A key feature of LS/ATN is the integration of real-time track and trace data feeds from on-route vehicles, which act as feedback measures to the optimizer engine. This allows continuous adaptation and regeneration of dynamic route plans based on the real world environment. Close integration with key pervasive technologies such as GPS and reliable multi-network communication offers the ability to enhance core system intelligence with fast, timely and accurate measures of the live environment [4]. Continuous transmission of vehicle state and location information provides live feedback metrics for the optimization platform, allowing human dispatchers to improve the efficiency of entire fleets. This flexibility enables logistics providers to react quickly to new customer requirements, rapidly altering transport routes to accommodate unexpected events and new orders.

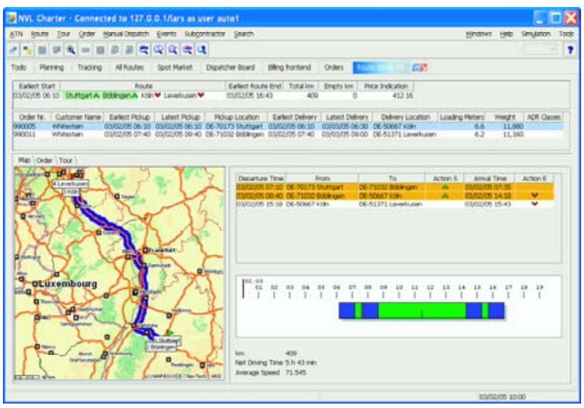

Figure 1. Details of a route in the LS/ATN dispatching support system, as suggested by an optimizer agent

This paper examines these issues by first describing the core optimization process of the LS/ATN planning and scheduling system for road freight transportation. A selection of the most relevant pervasive technologies currently available to support this decision support system with real-time data-feeds is then reviewed, followed by an analysis of how these technologies can integrate with LS/ATN to bring about direct benefits to the route optimization process. The article concludes with a discussion of progress and open challenges.

2. Intelligent Route Optimization

Today most logistics companies use computational tools, collectively known as Transport Management Systems (TMS), such as Transportation Planner from i2 Logistics, AxsFreight from Transaxiom, Cargobase, Elit and Transflow, to plan their transportation network from a strategic level all the way through to sub-daily route schedules. However, many TMS are unable to adequately handle unexpected events and generate plan alterations in real-time. When dealing with large numbers of distributed customers, limited fleet size, last minute changes to orders, or unexpected non-availability of vehicles due to traffic jams, breakdowns or accidents, static planning systems suffer from limited effectiveness. Significant human effort is required to manually adapt plans and control their execution.

In addition, vehicles can be of different types and capacities, are usually available at different locations and drivers must observe regulated drive time restrictions. To cope with all this, new, intelligent approaches to route planning are emerging that are capable of continuously determining optimal routes in response to transportation requests arriving simultaneously from many customers. The key challenge lies in allocating a finite number of vehicles of varying capacity and available at different locations such that transportation time and costs are minimized, while the number of on-time pick-ups and deliveries, and therefore customer satisfaction, are maximized.

2.1.Real-Time mPDPSTW Route Optimization

One means to tackle this optimization problem is by considering it as a multiple Pick up and Delivery Problem with Time Windows (mPDPTW) problem [5] which concerns the computation of the optimal set of routes for a fleet of vehicles in order to satisfy a collection of transportation orders while complying with available time windows at customer locations.

To solve the real-world challenge to an acceptable degree it is even necessary to add another two aspects. First the capability to react in real-time and second to deal with time constraints in a flexible manner, use penalty costs to decide between a new vehicle or being late. This results in the even more complex Multiple Pick up and Delivery Problem with Soft Time Windows in Real Time (R/T mPDPSTW).

Thus, in addition to a pickup and delivery location, each order includes the time windows within which the order must be picked up and delivered. Vehicles are dispatched from selected starting locations and routes are computed such that each request can be successfully transferred from origin to destination. The goal of R/T mPDPSTW is to provide feasible schedules, which satisfy the time window constraints for each vehicle to deliver to a set of customers with known demands on minimum-cost vehicle routes.

Another aspect is the capability to suggest charter trucks (dynamically add resources) when appropriate – when charter trucks are cheaper than own existing trucks.

To dynamically solve the R/T mPDPSTW problem, the LS/ATN transportation optimizer [3] used by DHL throughout Europe, segments and distributes the problem across a population of goal-directed software agents. Built on a bottom-up optimization philosophy, goal-directed agents cooperate to exchange client orders between one another, adjusting their schedules accordingly with the goal of minimizing the overall cost. Similar to human decision-making, solutions to problems arise from the interaction of individual decision makers (represented by software agents), each with its own local knowledge. The centralized, batch-oriented nature of traditional IT systems imposes intrinsic limits on dealing successfully with unpredictability and dynamic change. Multiagent systems are not restricted in this way because collaborating agents quickly adapt to changing circumstances and operational constraints. For real-time route optimization, it is simply not feasible to re-run a batch optimizer to adjust a transport plan every time a new event is received. Reality has shown that events such as order changes occur, on average, 1.3 times per order. Distributed, collaborating software processes, i.e., agents, can however work together by partitioning the optimization problem and following the bottom-up approach, thereby solving the optimization in near real-time.

In Figure 2, we show the integration of LS/ATN into the main dispatching process and how it interacts with the transportation environment.

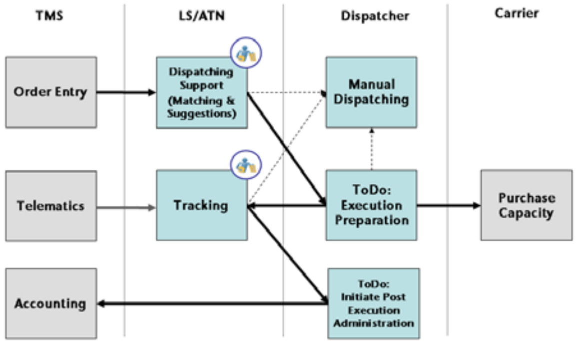

Figure 2. The main operating process of LS/ATN.

Client orders are received by the LS/ATN system through communication with the Transportation Management System (TMS) Order Entry functionality. The client data is processed by the *Dispatching Support* module of the LS/ATN system. Routes are computed based on inter-agent cooperation, and improved with the agent-based optimization algorithms described below. The plan obtained from this collaborative processing is then reported to the dispatcher for execution, and optionally for manual dispatching. The final routes accepted for execution and potentially adapted with manual dispatching are ordered for execution to a carrier and reported to the *Tracking* module of the LS/ATN system. The tracking module supports tracking and event handling for orders and trucks during the execution phase of the transport. Once this is finished it sends the routes back to the dispatcher for post execution administrative operations. The final decisions regarding costs are reported to the accounting module of the TMS system.

For R/T mPDPSTW optimization, an agent represents a geographical region, or business unit, with freight movement modeled as information flow between the agents - see Figure 3. Incoming transportation requests are distributed by an AgentRegionBroker (not shown) to the AgentRegion-Manager governing the region containing the pickup location. The number of such agents depends on the customer's setup of (regional) business units and varies between 6 and 60 for current deployments. In the larger case, 10000 vehicles and up to 40000 order requests are processed daily. This implies that no more than a few seconds are available to re-optimize a transportation plan when, for example, a new order must be integrated. Each AgentRegionManager generates a transportation plan specifying which orders to combine into which routes and which vehicles should be assigned to those routes. Agents exchange information using a negotiation protocol to sequentially insert transportation requests, while continually verifying vehicle availability, capacity and costs.

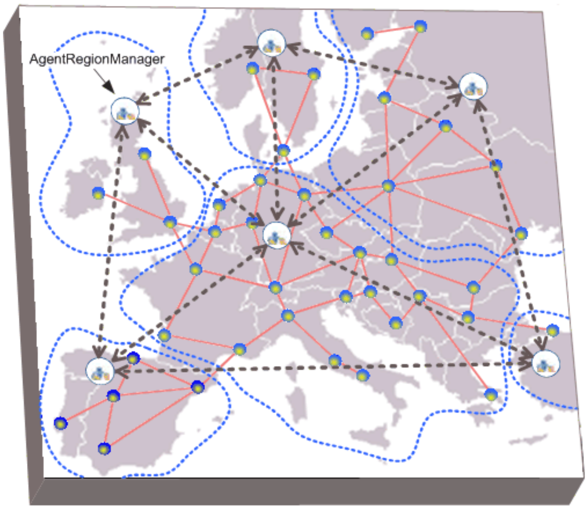

Figure 3. Illustration of freight transportation in Europe partitioned into 6 regions each with its own AgentRegionManager. Blue circles represent major transport hubs and red lines indicate example routes connecting hubs.

The optimization process incrementally reflects the dynamics of the underlying mPDPSTW settings. Whenever a new transport order is entered into the system, the current delivery plan is updated. This is achieved in a two-phase approach: (1) a new, valid, solution is generated including the new transportation request, then, (2) the obtained solution is improved through negotiation between the agents over the possibility of exchanging orders in order to reduce overall costs. The algorithm used to assign an order to a truck is a sequential insertion of orders [13]. All available trucks under control of the AgentRegion-Managers are checked as to whether they are able to transport the order, and the implied level of costs incurred. The order is assigned to the truck with the least additional costs.

Sequential insertion with requests for quotes to all trucks potentially produces suboptimal solutions. See for instance the example given in Figure 4. Order 1 is the first to arrive in the system and is assigned to truck 1's route. Order 2 is also optimally assigned to truck 1's route since that produces least additional costs (and kilometres). When order 3 arrives truck 1 is fully loaded, therefore a new truck 2 is used for order 3 and later for order 4. In order to improve the solution a further optimization step is performed by cyclic transfers between trucks. A cyclic transfer is an exchange of orders between routes. Figure 5 shows how the suboptimal example in Figure 4 is improved by a transfer of order 2 from route 1 to 2 while order 4 is transferred from route 2 to 1.

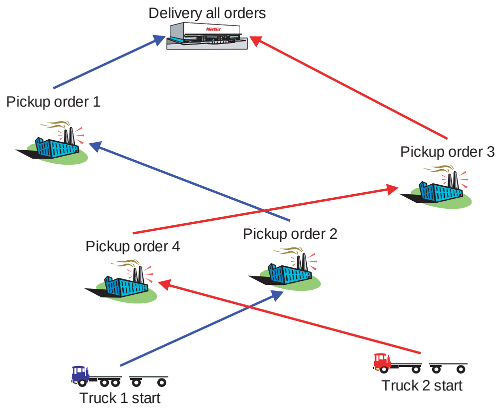

Figure 4. Example of a suboptimal solution given by the insertion algorithm for 4 orders.

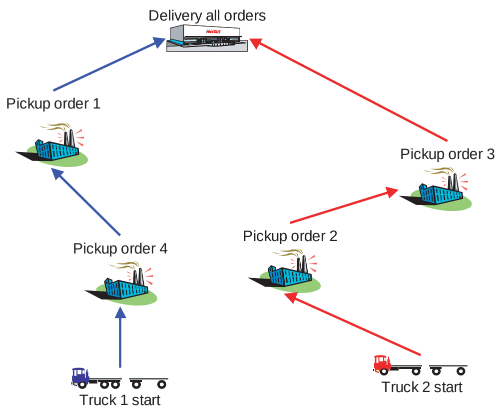

Figure 5. Optimal solution, for the example given in Figure 4, after an order transfer.

The optimization procedure must determine which transfers should be triggered. The AgentRegion-Manager therefore starts a negotiation process with the truck that was most recently changed. That truck is initiating transfer requests to all other trucks under control of the AgentRegionManager. From all the requests the most significant cost-saving transfer is performed. This changes the routes of both trucks involved. This hill climbing process is then continued with all changed routes until no more cost-saving exchanges can be achieved.

While the optimization function is 100% cost-based, other objectives must be satisfy when calculating routes. Some of these constraints are compulsory (hard), such as capacity and weight limitations of the vehicle, customer opening hours, that pickup date is before delivery date, and that pickup and delivery are performed by the same vehicle. Other soft constraints can be violated with a cost penalty, such as missing the latest possible pickup time or delivery time.

2.2. Performance in the Field

The major goal of logistics companies is reduction in transportation costs, although there are other KPIs such as kilometers driven and solution quality are also highly relevant as optimization targets. Transportation cost is most readily reduced by achieving higher utilization of transportation capacity, naturally resulting in a reduced number of driven kilometers and fewer required vehicles.

A partial dataset from our major customer, DHL Freight, contains around 3500 real-business transportation requests. In terms of the optimization results gained by comparing the solution of manual dispatching this requests against processing the same orders with LS/ATN, a total of 11.7% cost savings was achieved, where 4.2% of the cost savings stem from an equal reduction in driven kilometers. An additional achievement is that the number of vehicles used is 25.5% lower compared to the manual solution. The cost savings would even be higher if fixed costs for the vehicles were feasible, which is not the case in the charter business, but possibly in other transportation settings.

LS/ATN agent-based optimization guarantees a higher service level in terms of results quality. The high solution quality corresponds to a reduced number of violated constraints. The system allows the desired level of service quality to be fine-tuned. Figure 6 presents results obtained from LS/ATN relative to the manual dispatching solution. The first proposed solution (ATN1) provides a reduction of 8.33 % in driven kilometers at the same service level with no more than 25% of violated constraints. Moreover, this solution provides also a reduction of 8% in terms of kilometers driven with empty trucks. The second solution (ATN2) provides a reduction in driven kilometers of 0.78% relative to the manual dispatching solutions, while providing a significant higher service level: only 2.5% of violated constraints with more than 6h delay. The third solution (ATN3) provides an increase of only 1.66% in terms of driven kilometers, while meeting all the constraints to 100%.

Through the use of the automatic optimization a lower process cost is being achieved. This is due to automatic handling of plan deviations and evaluation of solution options in real-time. Moreover, through automation the communication costs in terms of dispatcher's time and material is reduced. Better customer support can be guaranteed through fast, comprehensive and up-to-date information about order execution. Automation also allows processing of a higher number of orders than with manual dispatching. This is an important issue as the size of data to be managed is increasingly growing. Other advantages of using LS/ATN are cost transparency and seamless integration with various TMS.

2.3. Integrating Real-time Vehicle Data

Although capacity and route optimization tools are proven to produce significant reductions in operating costs, many in the transportation industry are acutely aware that one key and often missing component of the optimization strategy is the provision of real-time feedback from en route vehicles. The objective is an intelligent transportation management system with every vehicle providing up-to-date information of progress through a pickup/delivery schedule and with on-board sensors detecting, for example, when freight is loaded and unloaded, and whether its condition (e.g., temperature) is within tolerance limits.

The 'intelligent transportation management systems' model [7] developed within the transportation industry is grounded with the principle of vehicle tracking and incorporation of real-time information into the transportation management process using available pervasive technologies. The emerging approaches to realizing this model involve various combinations of pervasive technologies, some of which are all highlighted in the following section.

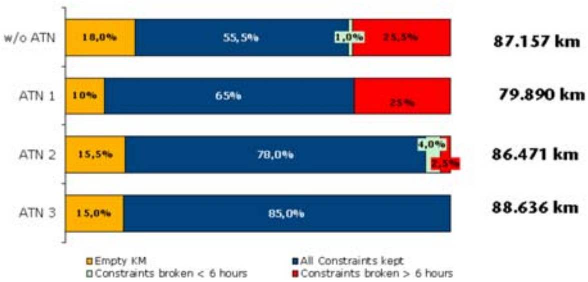

Figure 6. Improvements obtained with LS/ATN over manual dispatching

3. Pervasive Technologies

To provide live data feeds to a route optimizer such as LS/ATN, freight vehicles are equipped with a variety of pervasive technologies capable of measuring, coordinating and communicating information. This section highlights some of the most relevant technologies in use today, or in the early phases of adoption. LS/ATN is able to make use of data sourced from, manipulated or transmitted by any of these technologies to enhance the route optimization process.

3.1. On-Board Units and Vehicle State Sensors

An OBU, otherwise known as 'the black box', is a vehicle-mounted module with a processor and local memory that is capable of integrating other on-board technologies such as load-status sensors, digital tachographs, toll collection units, on-board and fleet management systems, and remote communications facilities. The majority of OBUs in use today, such as the VDO FM Onboard series from Siemens, the CarrierWeb logistics platform and EFAS from DelphiGrundig, are typically used to record vehicle location, calculate toll charges and store vehicle-specific information such as identity, class, weight and configuration. Some emerging OBUs will have increased processing capabilities allowing them to correlate and pre-process collected data locally prior to transmission. This offers the possibility of more computational intelligence installed within the vehicle enabling in-situ diagnostics and dynamic coordination with the remote planning optimizer such that the vehicle becomes an active participant in the planning process, rather than simply a passive provider and recipient of data.

Vehicle data, in its most common form, relates to the state of the vehicle itself, including, for example, tire pressure, engine condition and emissions data. Automatic acquisition of this data by on-board sensors and its transmission to a remote system has been available within the automotive industry from some years and is now gaining substantial interest in the freight transportation business. The OBU gathers information from sensors with embedded processors capable of detecting unusual or deviant conditions, and informs a central control center if a problem is detected. Sensors also measure the status of a shipment while on route such as detecting whether the internal temperature of refrigerated containers is within acceptable tolerance limits.

3.2. Automatic Freight Identification and Security

Many assets, including freight containers, swap-bodies, and transport vehicles, are now being fitted with transponders to not only identify themselves, but also to detect shipment contents and maintain real-time inventories. In the latter case, units are equipped with RFID readers tuned to detect RFID tags within the confined range of the container. Some tags, such as the Intermec Intellitag with an operating range of 4 meters, are specifically designed for pallet and container tracking, where tags are attached to every item and automatically scanned whenever cargo is loaded or unloaded. The live inventory serves as both, local information for the driver and as real-time feedback to the TMS, which uses it for record keeping and as input to the real-time route planner.

In addition, e-seals, whether electronic or mechanical, are now often placed on shipments or structures to detect unauthorized entry and send remote alerts via the OBU. E-seals on a container door can also store information about the container, the declaration of its contents, and its intended route through the system. They document when the seal was opened and, in combination with digital certificates and signatures identify whether the people accessing the container are authorized to do so.

3.3. GPS for Automatic Vehicle Location

Automatic vehicle location uses GPS signals for real-time persistent location monitoring of vehicles. Both human dispatchers and route planners like LS/ATN then can track vehicles continuously as they move between pickup and delivery locations. Active GPS systems allow automatic location identification of a mobile vehicle – at selected time intervals the mobile unit sends out its position, as well its speed and other technical information. Passive GPS uses the OBU to log location and other GPS information for later upload. Accuracy can vary, typically between 2 and 20 meters, according to the availability of enhancement technologies such as the Wide-Area Augmentation System (WAAS), available in the U.S. The European Galileo system will augment GPS to provide open-use accuracies in the region of 4-8 meters within the European region.

The adoption of GPS is growing quickly as the technology becomes commoditized, but some transportation companies remain reliant on legacy equipment for measuring vehicle location. Some of the alternatives to GPS in use today include dead-reckoning, which uses a magnetic compass and wheel odometers to track distance and direction from a known starting point, and the LORAN-C (Long Range Navigational) system which determines a vehicle's location using in-vehicle receivers and processors that measure the angles of synchronized radio pulses transmitted from at least two towers of predetermined position. Another system in use by some transportation companies is cell phone signal triangulation, which estimates vehicle location by movement between coverage cells. This only offers accuracy typically in the region of 50-350 meters, but is a cheap and readily available means of determining location.

3.4. Mobile Communications

Electronic communication is the key enabler of pervasive technologies. In transportation the most basic form is use is the SMS, which is commonly used to communicate job status such as when a driver has delivered an order. Technology is already in place to automatically process SMSs and input the data into the route planner. Also now in relatively widespread use is Dedicated Short-Range Communications, DSRC, operating in the short-range 5.8-5.9 GHz microwave band for use between vehicles and roadside transponders. Its primary use in Europe and Japan is for electronic toll collection. DSRC is also used for applications such verifying whether a passing vehicle has a correctly operating OBU.

Currently, the technology with the greatest utility is Machine-to-Machine [9] (M2M) communication, which is the collective term for enabling direct connectivity between machines (e.g., a vehicle's OBU and the remote planning engine) using widespread wireless technologies. Legacy 2G infrastructure is most commonly used as 3G technologies enter the mainstream for day-to-day human telecommunications. M2M is quickly emerging as a principle enabler of networked embedded intelligence, the cornerstone of pervasive computing. It can eliminate the barriers of distance, time and location, and as prices for the use of 2G continue to drop due to continued roll-out of 3G technologies, many transportation companies are taking advantage and adopting M2M as their primary means of electronic communication.

Emerging solutions take M2M to another level by enabling always-on and highly reliable communication through automatic selection of connection technology, e.g., GPRS, EDGE, UMTS, Satellite Services and WiFi according to availability. The LS/ATN route optimizer, for example, can be augmented with a remote connection agent module [10] installed in vehicles that offers seamless M2M over cellular technologies, Wireless LAN and even short-range ad-hoc connections if available. The particular selection of communication technology can be made either manually or automatically, depending on several metrics including location, connection availability, transmission cost and service type or task. For example, a fleet operator may prefer the use of satellite to directly communicate with a driver, but then a combination of cellular technologies for remote monitoring, trailer tracking, and diagnostics. Low cost GPRS might be selected to download position coordinates from an on-board GPS; whereas, a higher-bandwidth (and cost) option such as UMTS/WCDMA might be preferred for an over-the-air update to the OBU or on-board sensors.

4. Route Optimization with Integrated Pervasive Technologies

Transportation route optimizers can take advantage of real-time data sourced from vehicles equipped with pervasive technologies by incorporating information relating to vehicle location, state and activity into their planning processes. The LS/ATN optimizer uses the following sequence of operations to sense, process and act on this data, as illustrated in Figure 7.

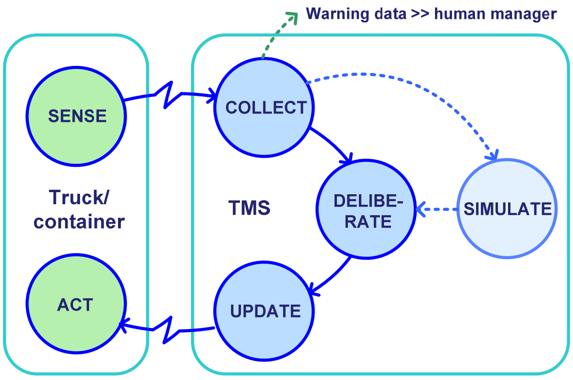

Figure 7. Information flow from on-board sensors is processed to produce a re-optimized route that is issued back to a vehicle as an updated schedule.

Sense – Periodically gather data from on-board vehicle sensors. Consolidate this data with an OBU and perform pre-processing if necessary or possible, i.e., to improve precision and reduce error rate by integrating across multiple readings. This data is then transmitted to the remote route planner using M2M technology over a selected mobile network.

Collect – At the TMS, collect incoming data from vehicles on the road and shape it using codecs into forms suitable for the live route optimizer, e.g., by mapping geographical coordinates onto known positions. The position information of a single vehicle is used to immediately adjust dispatching plans in the case of deviations (described below in more detail). If the number and density of vehicles in a region is high enough, this ‘floating vehicle data’ may be integrated into a map containing real-time traffic flow information [11]. This data is input to real-time routing systems to plan the fastest route taking into account current traffic flow and congestion information. Other than information sourced from vehicles themselves, additional external data feeds can help tune the route optimization yet further. These include, for example, third-party sources providing traffic congestion information, location of road works, weather forecasts and delays at shipping or airfreight hubs.

Simulate – A secondary layer of the optimization process consists of background simulations where alternative schedules are proposed, offering projections of future routes based on real-time data, predicted events and probabilistic estimates of pickup and delivery times. Simulations are conducted as separate optimization processes extrapolating from a live session, but with the occasional (random or planned) introduction of hypothetical event data, such as a new order or a vehicle breakdown. Results can be used either as rolling input to the scheduling decision process or to assist with strategic decision making when determining the impact of, for example, adjustments in vehicle numbers, staffing levels and scheduling of freight consolidation at distribution hubs.

Deliberate – Input collected, and optionally simulated, data into the route optimization process to produce schedule updates to be transmitted to affected vehicles. The most common use of this input data by the planner is for the management of delays. Once the planner has knowledge of a delivery delay, it checks if the plan remains valid or if some orders with later delivery times can now be better transported with other vehicles. The dispatcher is immediately informed if this is the case, with the real-time planner generating various deployment options.

Real-time data also improves optimization if the system receives a new order. In this case a transport planner without real-time data feeds can assign the order only to vehicles that have yet to start a trip or, if at least pickup or delivery feedback is available after the next pickup or delivery location. This is because the planner has no knowledge of where on the road the vehicle is currently located. With real-time feedback the exact position is known at all times, implying of course that re-planning is possible at any time. For example, a truck has an order to pick up in Zurich and deliver to Berlin. After the truck has left Zurich, a new order arrives to be picked up in Stuttgart and also delivered to Berlin. Without exact knowledge of the truck’s position at the time the order arrives, it is not possible to precisely check if the order may be transported with this truck. A perfect opportunity for co-loading is missed.

In a similar fashion, the feedback of real-time data is used to exploit opportunities when the truck is ahead of schedule. This is usually the case if loading or unloading takes less than the expected time, or, on occasion, if the drive time is less than expected. In such cases, orders that did not originally fit into the truck’s schedule, and thus had to be transported separately, may now be transported with this truck.

Again, the faster the planner knows of such situations the less likely it is that opportunities are missed.

Update – Once new route plans have been devised, verify them and upload them to vehicles via their M2M connection. Additional information such as firmware upgrades can also be transmitted if and when necessary.

Act – On board the vehicle, whenever new scheduling is received, locally stored information is updated to inform the driver of re-planning. If the container has an RFID scanner installed, a scan of current freight will be compared against the new schedule to verify compliance. If other data, e.g., firmware upgrades, are received, they are installed automatically.

In particular, during the deliberation phase, route optimization and the derivation of schedules can directly use both information relating to vehicles movements as they proceed through delivery schedules and feedback from RFID transponders notifying when orders have been added to or removed. This real-time component implies that time windows can be more finely tuned according to current events, resulting in alternative schedules that can either compensate for delays or take advantage of time saved. Preliminary results with a prototype demonstrate that employing real-time data in the optimization process can further reduce transportation operating costs by up to 3% beyond the 5-10% achieved from the standard optimization process described earlier - depending on the particular business case, order structure and system configuration.

5. Challenges and Conclusions

There remain many scientific and practical challenges related to the design and use of real-time dispatching and optimization systems. A selection of these we consider as relevant to LS/ATN and for consideration by the community at large are as follows:

A major challenge is the effective handling of inter-company, inter-region and inter-modal transportation. Transportation intrinsically involves multiple carriers operating both within and across sectors (i.e., road, air, and shipping) and across geographical boundaries. Each carrier has their own, often proprietary, systems that do not necessarily integrate easily with one another. Addressing this integration problem is a significant engineering issue to be faced as the technologies addressed in this article come into more widespread use.

The integration of transportation planners into supply chain and production systems is also important. As previously mentioned, freight is now often delivered directly to manufacturing plants without passing through transitional storage. Integration of these systems thus becomes a priority when shaping dynamic supply chains, and supply networks.

OBUs in use today typically consist of a simple processor, memory and communication interfaces. Installed software is often designed solely for reading data from sensors and transmitting it to the TMS. One method of improving on this design is the integration of an autonomous software controller into the OBU to assist with the manipulation and coordination of collected on-board data. Example uses include assisting in the selection of M2M connection type in a multi-provider environment according to the type and volume of data to be transmitted and caching data locally if connections are temporarily unavailable. The controller can be further extended with a software agent that extends the distributed intelligence offered by the TMS optimizer. This agent essentially acts as a remote extension of the optimization platform allowing the agent to act as a proxy representative of the vehicle itself within the context of route scheduling. Vehicles can thus become active participants in the planning process, forming a network overlay of communicating data processors.

Further research is required on so-called 'smart' freight containers capable of announcing their presence and even negotiating with external devices. For example, a simple OBU fixed to a container will allow it to communicate with vehicles, customs checks and equipment at freight consolidation centers. Many major transportation companies use such centers, distributed at strategic locations, with the primary goal of consolidating freight onto as few vehicles as possible to maximize use of available capacity. With the installation of RFID readers, incoming freight with RFID tags can be traced as it moves through a facility, providing TMS optimizers with complete coverage of freight location throughout its entire lifecycle within the business chain.

In addition, external factors also favor early adoption of pervasive technologies, such as the ongoing escalation of fuel prices and constant increases in demand for fast, high-volume freight shipping. This is recognized in the European Union white paper, "European Transport Policy for 2010" [12] which discusses the use of intelligent information services integrated with route planning systems and mobile communications to provide real-time, intelligent end-to-end freight and vehicle tracking and tracing.

There can be little doubt that the adoption of intelligent transportation planners capable of using real-time data sourced from pervasive technologies, such as those discussed in this article is a major objective of many freight transportation operators both in Europe and other areas of the world. With these techniques now widely recognized as an important means of reducing operating costs, many companies are already well advanced on the path to adoption.

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