AN OPERATIONS SUPPORT SYSTEM FOR TRUCKAGE COMPANIES

Asvin Goel and Volker Gruhn
Chair of Applied Telematics / e-Business, Department of Computer Science,
University of Leipzig, Klostergasse 3, 04109 Leipzig, Germany,
{goel,gruhn}@ebus.informatik.uni-leipzig.de

Abstract: In this paper we present a concept of an operations support system for truckage companies. The operations support system uses real-time information obtained from telematics systems to support the dispatchers in managing the carrier's operations. Messages sent from the vehicles are automatically analysed and actual data, such as exact arrival and departure times, as well as discrepancies between actual and planned data are identified. The automatically analysed information is used to dynamically calculate improved schedules. The underlying optimisation method is capable of taking into account that input data may change at any time and that dispatchers can concurrently modify the schedule.

Keywords: Decision Support Systems, Transportation Systems, Operational Logistics, Logistics Management, e-Logistics

1 Introduction

Due to globalisation, liberalisation of markets, deregulation in the transport sector, and the increasing commitment to the just-in-time philosophy, competition between motor carriers and expectations on punctuality, reliability, flexibility, transparency and quality of transportation services have increased significantly and will increase even more in the future. Rapid development of mobile communication and information technology allows the use of telematics to cope with those challenges and to increase the efficiency of carrier operations. Vehicles can be equipped with on-board units, consisting of input devices and a positioning system. The vehicle systems can communicate with a stationary system in the dispatching office and thus, can help in closing the gap between what is known to the drivers and what is known to the dispatchers in the dispatching office. Those systems provide the necessary information required to support the management of carrier operations. In this paper we present a concept of an operations support system for truckage companies which is a decision support system which, furthermore, supports dispatchers in managing the carrier's operations. This is done by automatically analysing the information retrieved from telematics systems. The operations support system relieves dispatchers in gathering and analysing relevant data, supports the dispatchers in taking appropriate actions when problems arise, and assists dispatchers in making schedules in real-time considering the actual data. It can improve schedules considering changes concurrently made by the dispatchers. The remainder of this paper is organised as follows. First, we give a short overview over related work. Then, we describe the architecture of the operations support system and the functions of its subsystems. Eventually, we present some practical experiences.

2 Related work

According to Roy (2001), telematics systems provide the necessary information required to achieve real-time computer-based decision support. However, only few decision support tools can be found that integrate real-time information sent by the vehicles. So far no universal solution exists that is suitable for any motor carrier, and many of the systems available today still require that the data is manually transfered between logistics application and the fleet telematics system – a time consuming and error prone task. Yet, some techniques to use real-time information to support the management of motor carrier operations have been developed. For example, Erkens and Kopfer (2001) propose a concept for managing a truck fleet through cell-phones and the internet. Gruhn et al. (2003) have proposed a mobile communication system, which focuses on the driver/dispatcher interaction and the integration with logistics software. Goel and Gruhn (2005a) present a concept for the integration of an off-the-shelf telematics systems into the carrier's IT infrastructure. Incoming messages are automatically analysed and put in context to the managed objects in the carrier's information system. Those systems improve the information flow and support the decision making by making reliable information available. They eliminate a major problem for successful deployment of real-time planning systems, which is according to Powell et al. (2002), the lack of information.

The development of algorithms for dynamic vehicle routing problems is an active research field and several algorithms have been proposed recently, for example, by Yang et al. (2004) and Fleischmann et al. (2004). Most of the dynamic optimisation methods in literature concern event driven optimisation. That is, the methods are only used when input data to the optimisation model change. Those methods aim at quickly calculating new schedules when input data change. However, they do not improve solutions during the idle time of the system, i.e. the time in which no significant external changes become known. Iterative improvement methods which can be used to improve schedules when data has changed as well as in the idle time of the system have been presented by Goel and Gruhn (2005b, 2005c). Theses approaches are characterised by the capability of handling various real-life requirements and by very fast response times, i.e. the time required for one iteration of the algorithms is very fast and thus, they can be used in dynamic problems where input data may change frequently.

3 System architecture

The architecture of the operations support system is illustrated in Figure 1 using the Unified Modeling Language. The core of the system is the Order & Fleet Management System (OFMS) which has the central role concerning the management of orders and vehicles. A Messaging & Fleet Telematics System (MFMS) is connected to the OFMS and a Fleet Telematics System consisting of mobile Vehicle Systems (VS) and a stationary Fleet Communication System (FCS). The MFMS exchanges information between the FCS and the OFMS analyses incoming messages and puts the resulting data in context to the data stored in the OFMS. A Dynamic Planning System (DPS) can use the hereby obtained real-time information to optimise the schedule considering the actual data concerning the vehicle fleet and orders. The OFMS, MFMS, DPS, and VS may be connected to a Traffic Observation & Travel Time Estimation System in order to consider actual traffic conditions. Several other subsystems can be connected to the OFMS, for example, a Billing

System for the generation of invoices, a Cost & Performance Analysis System for the identification of unnecessary costs and performance measurements of the carrier's operations, and a Load Acquisition & Freight Exchange System for the acquisition of additional load or the employment of external carriers for loads which cannot be efficiently served by self-operated vehicles. These subsystems, however, are not in the scope of this work.

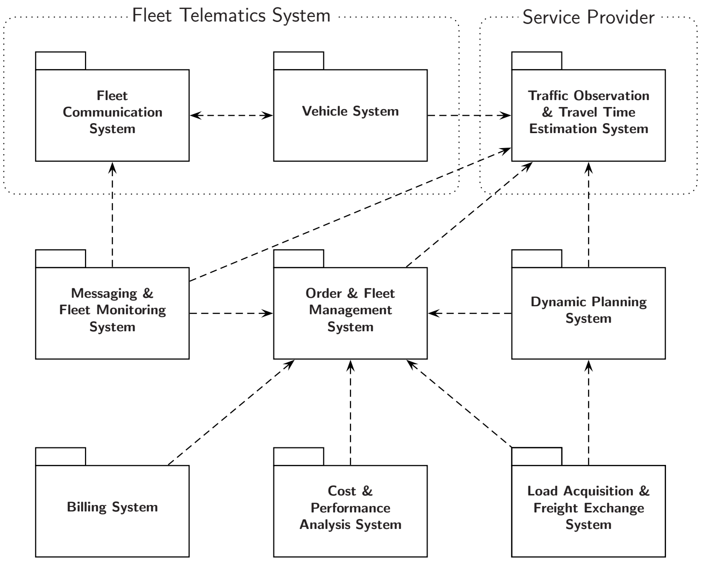

Figure 1: System architecture

As illustrated in Figure 2, the OFMS provides all necessary functionalities for the dispatchers to manage the carrier's operations. Dispatchers can store and retrieve all necessary data concerning vehicles and orders as well as the current schedule. The OFMS supports the dispatchers by providing graphical user interfaces where filtered information necessary for decision making are presented.

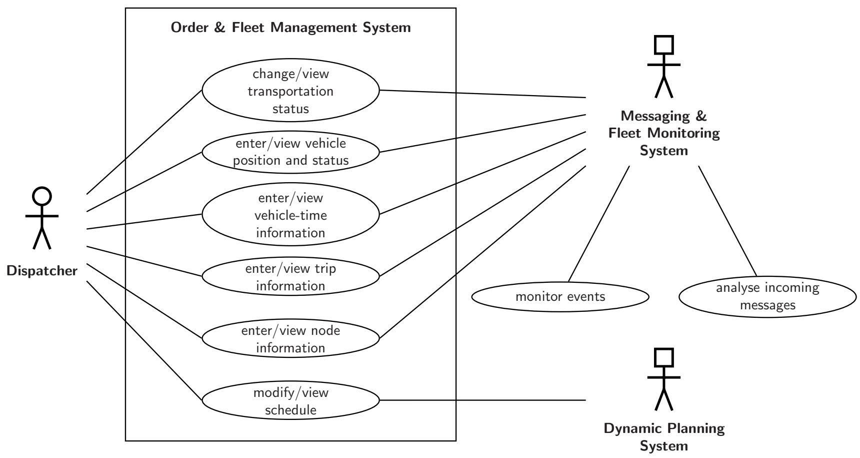

Figure 2: Actors in the operations support system

The MFMS and the DPS take over the role of the dispatchers. Whenever the MFMS identifies any discrepancies between planned and actual data it adjusts the data in the OFMS. This allows the dispatchers to concentrate on the information received from the vehicles which cannot be unambiguously interpreted by the MFMS. The DPS continuously calculates improved schedules considering the actual conditions which have been entered into the OFMS by the dispatchers and the MFMS as well as manual decisions concerning the planned schedule. In the next sections the MFMS and the DPS are described in more detail.

4 The Messaging & Fleet Monitoring System

The Messaging & Fleet Monitoring System analyses all incoming messages as illustrated in Figure 3. When an incoming message is received, it is stored in the OFMS. Then, the message is analysed according to its potential content. Different data can be sent from the drivers or vehicle systems to the dispatching office. If vehicles are equipped with a GPS (Global Positioning System) receiver they can regularly submit the vehicle's position. Drivers can push predefined status buttons and may add numerical values to the messages. Sensors can give other important information, for example, the opening of the rear door which indicates the begin of handling activities.

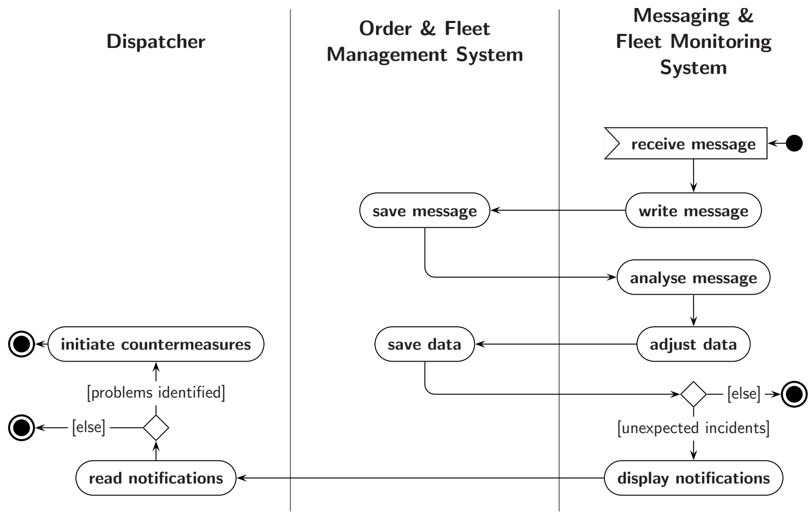

Figure 3: Analyse message

This data is analysed automatically and the information obtained is stored in the OFMS. The MFMS detects the arrival and departure times at handling locations, calculates expected arrival times considering the current vehicle position, and detects unexpected incidents. Dispatchers are automatically notified in case of detected incidents or obscurities. Thus, the dispatchers can concentrate on those messages which cannot be automatically interpreted or where unexpected incidents were identified. Countermeasures can be initiated by the dispatchers if they identify any problems.

The MFMS can furthermore, support the dispatchers by monitoring all events which are expected to occur. For example, if an order is assigned to a tour of a vehicle, but the driver hasn't yet been instructed, the MFMS calculates the latest time when the driver has to be instructed about his new task. This is done considering the vehicles current position and the time needed for the driver to reach its next destination. The MFMS notifies the dispatchers when a driver has to be instructed urgently. It also monitors the communication process and warns dispatchers if no confirmation was sent by the driver in time after the instruction has been sent to him.

5 The Dynamic Planning System

According to Powell et al. (2002) the major problem for successful deployment of dynamic planning systems is the availability of up-to-date information about the actual state of the transportation system. The MFMS closes the gap between what is known to the drivers and what is known to the dispatchers in the dispatching office. Furthermore, the up-to-date information is available to the OFMS without the need of manually keying in the data. This data can be used for dynamic planning, however, several fundamental problems arise in computerised optimisation of dynamic real-life problems:

- deviations between planned and actual state of the transportation system may result in infeasible schedules, for example, if vehicles are delayed the revised arrival times may not be feasible according to time window restrictions,
- schedules calculated by an optimisation method cannot always be applied as dispatchers and the MFMS can concurrently modify problem data,
- as any analytical model is an abstraction of the real-life problem some solutions which are feasible according to the analytical model may not be feasible in reality and vice versa, and
- a solution with high quality in the model may not have the same high quality in reality.

The first problem can be addressed by resolving infeasibilities resulting from disturbances in the transportation system. Some infeasibilities can be resolved by removing orders from the tours they are assigned to. This, however, is only possible if the corresponding shipments have not yet been loaded. In this case the order can be removed from the tour and may be inserted to the tour of another vehicle. Otherwise, the order has already been partially served and must be completed. The only possibility of resolving the infeasibilities is by relaxing the violated constraints, e.g. by modifying the time window constraints used by the optimisation method.

Efficient methods for maintaining data consistency are required to tackle the second problem, as otherwise, dispatchers and the optimisation method may concurrently assign the same order to different tours. Pessimistic locking can be used to prevent concurrent modifications concerning the same transportation request or tour. In pessimistic locking a data record to be updated is locked in advance, see (Elmasri and Navathe, 2000). Once the dispatcher has locked a data record he can make the required changes, and then commit or rollback. During the commit or rollback the lock is automatically dropped. Dispatchers who want to acquire a lock of the same data record during this process will have to wait until the current lock is dropped. The pessimistic locking scheme, although very simple and safe, does not fit well for dynamic optimisation as the optimisation method continuously tries to improve the schedule, and thus, would lock all data records during optimisation. This would prevent the dispatchers from performing any manual changes to the schedule. Optimistic locking, as described in (Elmasri and Navathe, 2000), is more convenient. Optimistic locking does not lock data records when they are read, and proceeds on the assumption that the data records being updated will not be changed. To ensure data consistency the optimistic locking scheme we propose involves reading a *Transaction Control Number* (TCN) along with each data record representing an order or a tour. When the schedule is changed by the dispatchers, the MFMS, or the DPS, the TCNs of the respective order and the tour are written back to the database when the record is updated. A pre-update trigger checks the value of the updated TCNs against those held in the database. If the TCNs do not match the transaction is rejected. If the TCNs match no other transactions have updated the data records since they were read. The TCNs of orders and tours are incremented with each successful update. The optimistic locking scheme allows several dispatchers and the optimisation method to concurrently modify the schedule and it prevents lockouts which may occur in pessimistic locking when one dispatcher selects a data record for update, and then leaves for lunch without finishing or aborting the transaction. In a lockout all other dispatchers who may want to modify that data record are forced to wait until the transaction is completed, or until the data base administrator kills the offending transaction and releases the lock.

The remaining problems can be addressed by allowing dispatchers to fix parts of the schedule, even if they are infeasible according to the analytical model. That is, dispatchers must be allowed to modify, remove, and add constraints, e.g. to prohibit an order to be removed from a tour or to be inserted to certain tours. Furthermore, dispatchers must be able to define which types of infeasibilities may be automatically resolved. For example, dispatchers may allow time window constraints to be automatically relaxed up to a certain degree. Any other infeasibility must be resolved manually.

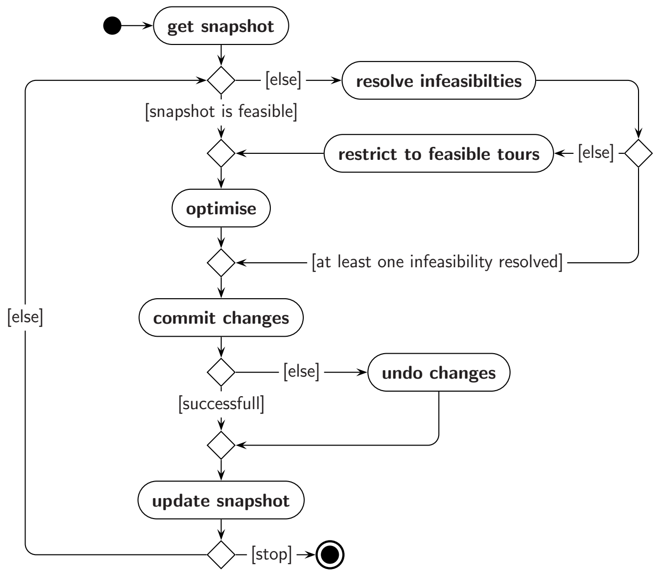

Figure 4: Dynamic planning

Figure 4 illustrates a Dynamic Planning System (DPS) capable of handling the problems discussed above. First, the DPS gets a snapshot of the current schedule. If there are any infeasibilities according to the analytical model the DPS tries to automatically resolve the infeasibilities. Any changes to the schedule are committed before the optimisation method is invoked. If no infeasibility can be automatically resolved, all infeasible tours and the orders assigned to these tours are removed from the optimisation model as they can not be properly handled by the optimisation method. Thus, when the optimisation method is invoked only feasible tours, orders assigned to feasible tours, and unscheduled orders are considered. The DPS tries to commit any changes made to the current schedule using the optimistic locking scheme. If successful the current snapshot is updated in order to consider all meanwhile changes in the data. Otherwise, the changes made on the snapshot by the DPS are undone before the snapshot is updated. The DPS continues with the next iteration until some stopping condition is met - which of course never is the case if the system is used in a rolling planning horizon.

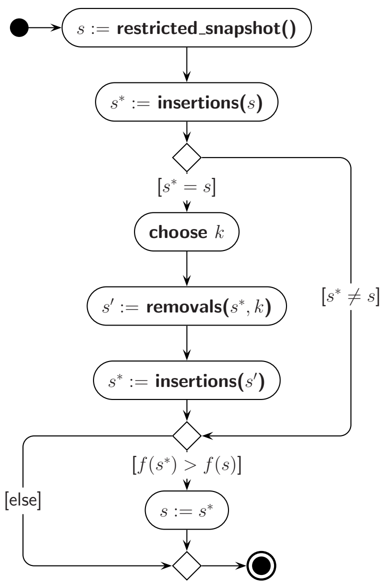

Figure 5: The optimisation method

Basic approaches for dynamic optimisation focus on the arrival of new transportation requests and the completion of a transportation process as the sole dynamic events. The methods proposed by Fleischmann et al. (2004) and Yang et al. (2004) assign open orders to tours and are only invoked if an event occurs. They do not use the idle time of the system in order to improve the current schedule. As illustrated in Figure 5 the optimisation method we propose starts with using an insertion method, for example, the auction method proposed by Antes and Derigs (1995) for the Vehicle Routing Problem with Time Windows. This approach can be easily extended to handle the various requirements of real-life Pickup and Delivery Problems. If no order can be inserted the optimisation method continuous with one iteration of *Large Neighborhood Search* (LNS). LNS has been presented by Shaw (1997) and has proven to be well suited for rich vehicle routing problems, see (Kilby et al., 2000). The basic idea of LNS is to start with an initial solution and to remove *k* orders from their tours. The number *k* of orders to be removed can be varied to increase diversification of the search. After these *k* orders are removed an insertion method tries to re-insert unscheduled orders. In other words, a part of the current schedule remains unchanged and the other part is re-optimised. The insertion method proposed by Shaw (1997) is not very fast and, therefore, we propose to use the auction method presented by Antes and Derigs (1995) to guarantee fast response times. If the objective function value of the new schedule is higher than the objective function value of the initial schedule the latter is replaced by the new one, otherwise, it is not modified.

6 Practical experiences

Georgi Transporte GmbH is a German motor carrier specialised in the road transport of so-called air-cargo between European airports. The carrier operates 140 vehicles equipped with mobile *fleetec III* systems (datafactory AG) which communicate with the stationary *DATAfleet* system (datafactory AG). The *fleetec III* systems consist of a display, configurable status buttons, and a GPS receiver. The communication is realised by using the Short Message Service (SMS) provided by the Global System for Mobile Communications (GSM). We have partially developed the operations support system. Travel times were assumed to be static and no Traffic Observation & Travel Time Estimation System was integrated into the system. The Dynamic Planning System was only developed as a prototype and is not yet in operation.

After the system was running for one year we asked Georgi Transporte GmbH about their experiences with the MFMS. They reported that the dispatchers were significantly relieved and at the same time the information flow was significantly improved. The improved availability of information eased getting a better overlook over the actual situation and thus, dispatchers were supported in managing the carrier’s operations. Unfortunately, no information about a possible reduction of empty mileage and costs resulting from better decisions accompanied with the improved information supply was given to us.

In order to provide a proof of concept we developed a prototype of the DPS which can be integrated into the carrier’s information system. The required optimistic locking scheme and the necessary infrastructure for synchronisation of data are already implemented in the OFMS. The prototype of the DPS allows interactive optimisation, that is, it allows the dispatchers to manually fix parts of the solution and to manually assign orders to tours or to remove orders from tours. The DPS optimises the schedule considering all changes made by the dispatchers and new orders entered into the system.

The DPS is based on Large Neighborhood Search which has proven to be well suited for rich vehicle routing problems. Goel and Gruhn (2005b, 2005c) have shown that the LNS approach can be significantly speeded up by using fast insertion methods. Furthermore, various requirements arising in real-life vehicle routing problems, for example, time window restrictions, a heterogeneous vehicle fleet with different travel times, travel costs and capacity can be handled by the LNS method. The methods presented in (Goel and Gruhn, 2005c) can also take into account restrictions to drivers’ working hours as regulated by EU social legislation. Computational experiments have shown that the methods proposed have response times of less than one second for problems with hundreds of vehicles and several hundreds of orders. The solution quality compared to event driven methods, which simply insert new orders when they become known, is significantly higher. The optimisation problem discussed by Goel and Gruhn (2005b, 2005c) differs from the problem considered in this paper primarily in the following aspects: any problem data may change at any time and parts of the schedule may be fixed by the dispatchers or may be infeasible. LNS does not use any kind of memory and has very fast response times. Thus, changes in the problem data will not have a big impact on the general effectiveness of LNS. The LNS approach is based on having a part of the current schedule unchanged and re-optimising the other part. As a result, the main difference which can be expected is that the restricted search space will be explored more thoroughly.

7 Conclusions

In this paper we have presented a concept of an operations support system for truckage companies. The operations support system uses real-time information obtained from telematics systems to support the dispatchers in managing the carrier's operations. Messages sent from the vehicles are automatically analysed and actual data, such as exact arrival and departure times, as well as discrepancies between actual and planned data are identified. Dispatchers benefit as they can concentrate on work which cannot be automated and which requires human decisions. The information gap between dispatchers and drivers is reduced and thus, decisions made by the dispatchers, are less likely to be in conflict with practical or legal requirements, e.g. regarding drivers' working hours. Furthermore, countermeasures can be initiated faster and in some cases even before irregularities have resulted in unnecessary costs. As information is analysed automatically, the prerequisites for dynamic planning are provided. Dynamic optimisation methods can be integrated into the operations support system allowing dispatchers to concurrently modify schedules, to add or relax constraints with respect to the optimisation model, and to modify input data as changes become known. An optimistic locking scheme has been presented which ensures data consistency when several dispatchers and the optimisation method simultaneously modify the schedule.

Up to now only parts of the operations support system are deployed. Our practical experiences have shown that the Order & Fleet Management System and Messaging & Fleet Monitoring System presented in this work have significantly improved the information flow and reduced the effort needed to enter all relevant data into the information system of the carrier. We have developed a prototype of the Dynamic Planning System presented in this paper which can be integrated into the carrier's system. It will be interesting to see and evaluate the Dynamic Planning System when it is used in practise. Computational experiments have shown that, although response times were less than one second, schedules can significantly be improved.

8 References

Antes, J. and U. Derigs (1995). A new parallel tour construction algorithm for the vehicle routing problem with time windows. Department of Information Systems and Operations Research, University of Cologne, Cologne, Germany.

Elmasri R. and S.B. Navathe (2000). *Fundamentals of database systems*. Third Edition, Addison-Wesley, Reading, Massachusetts.

Erkens, E. and H. Kopfer (2001). WAP-LOG: Ein System zur mobilen Fahrzeugeinsatzsteuerung und Auftragsfortschrittkontrolle. In: *Logistik Management - Supply Chain Management und e-Business*, Teubner Stuttgart.

Fleischmann, B., S. Gnutzmann and E. Sandvoß (2004). Dynamic vehicle routing based on on-line traffic information. *Transportation Science*, **38(4)**:420–433.

A. Goel and V. Gruhn (2005a). Integration of telematics for efficient management of carrier operations. In: *Proceedings of the IEEE International Conference on e-Business Engineering (ICEBE 2005)*, ISBN 0-7695-2430-3, 404–408.

A. Goel and V. Gruhn (2005b). Large Neighborhood Search for rich VRP with multiple pickup and delivery locations. In: *Proceedings of the 18th Mini EURO Conference on Variable Neighborhood Search (MEC-VNS)*, ISBN 84-689-5679-1.

A. Goel and V. Gruhn (2005c). Solving a dynamic real-life vehicle routing problem. In: *Proceedings of the International Scientific Annual Conference on Operations Research (OR2005),* 369–374. Springer (to appear).

Gruhn, V., R. Ijioui, M. Hülder, and L. Schöpe (2003). Mobile communication systems for truckage companies. In: *The Second International Conference on Mobile Business*, (G.M. Giaglis (Ed)), 337–344. Austrian Computer Society.

Kilby, P., P. Prosser, and P. Shaw (2000). A comparison of traditional and constraint-based heuristic methods on vehicle routing problems with side constraints. *Constraints*, **5**:389–414.

Powell, W.B., A. Marar, J. Gelfand, and S. Bowers (2002). Implementing real-time optimization models: A case application from the motor carrier industry. *Operations Research*, **50(4)**:571–581.

Roy, J. (2001). Recent trends in logistics and the need for real-time decision tools in the trucking industry. In: *HICSS '01: Proceedings of the 34th Annual Hawaii International Conference on System Sciences (HICSS-34)-Volume 3*, 3031, Washington, DC, USA, IEEE Computer Society.

Shaw, P. (1997). A new local search algorithm providing high quality solutions to vehicle routing problems. Technical report, APES group, Department of Computer Sciences, University of Strathclyde, Glasgow, Scottland.

Yang, J., P. Jaillet, and H. Mahmassani (2004). Real-time multi-vehicle truckload pickup-and-delivery problems. *Transportation Science*, **38(2)**:135–148.

9 Biography

Asvin Goel studied mathematics at the University of Göttingen. After finishing his studies he developed logistics software for the motor carrier industry. Since 2005, he is PhD student at the Chair of Applied Telematics/e-Business at the University of Leipzig. His main interests are Intelligent Transportation Systems and Operations Research.

Volker Gruhn is director and head of the Chair of Applied Telematics/e-Business at the University of Leipzig. The chair is endowed by Deutsche Telekom AG and is focusing on research concerning the development of mobile and distributed software systems.