Vehicle Routing in Practice 2008

Soria Moria Conference Center

Oslo, Norway, June 12-14, 2008

Final Program

VIP'08 - Final Program

Thursday June 12

1200-1230	**Opening Session**	
1200-1230	Geir Hasle	Introduction - Vehicle Routing in Practice

1230-1330 **Lunch**

1330-1500	**New VRP Variants I (Chair: Mikael Rönnquist)**	
1330-1400	Bruce Golden	The Consistent Vehicle Routing Problem
1400-1430	Richard Eglese	Vehicle Routing and the Green Agenda
1430-1500	Mikael Rönnquist	Synchronized vehicle routing

1500-1530 **Coffee**

1530-1730	**New VRP Variants II (Chair: Frederic Semet)**	
1530-1600	Michel Gendreau	Solving the Single-Vehicle Routing Problem with Stochastic Demands
1600-1630	Oli Madsen	The Double TSP with Multiple Stacks - Heuristic Solution Approaches
1630-1700	Dominique Feillet	Vehicle routing problems with alternative paths
1700-1730	Frederic Semet	New hybrid approaches for a location-routing problem

1800-1930 **Dinner**

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Friday June 13

0830-1000	**Applications**	**(Chair: Kenneth Sörensen)**
0830-0900	Johan Oppen	Livestock Collection
0900-0930	Wout Dullaert	Vehicle routing methodologies to support costing and pricing decisions
0930-1000	Kenneth Sörensen	A multiobjective distribution problem for parcel delivery at TNT

1000-1030 Coffee

1030-1230	**Vessel Routing**	**(Chair: Lars Magnus Hvattum)**
1030-1100	Truls Flatberg	Routing problems in maritime logistics
1100-1130	Henrik Andersson	The LNG Inventory Routing Problem with Pick-up Contracts
1130-1200	Frank Hennig	Optimizing a Maritime Split Pickup and Split Delivery Problem
1200-1230	Lars M. Hvattum	When feasibility of routes is difficult to determine: an example from maritime bulk shipping

1230-1330 Lunch

1330-1500	**Rich VRP**	**(Chair: Andreas Reinholz)**
1330-1400	Pierre Dejax	Multiperiodic VRP models and hybrid solution techniques for closed loops-reverse logistics
1400-1430	Jens Gottlieb	Solving Real-World Vehicle Scheduling and Routing Problems
1430-1500	Andreas Reinholz	A Process Oriented Modelling Concept for Rich Vehicle Routing Problems

1500-1530 Coffee

1530-1730	**Fleet Composition**	**(Chair: Wout Dullaert)**
1530-1600	Arild Hoff	Industrial Aspects and Literature Survey: Fleet Composition and Routing
1600-1630	Yuichi Nagata	A Powerful Route Minimization Heuristic for the Vehicle Routing Problem with Time Windows
1630-1700	Morten Smedsrud	A Route Minimization Heuristic for Rich Vehicle Routing Problems
1700-1730	Wout Dullaert	Adaptive Diversification Metaheuristic for the Fleet Size and Mix Vehicle Routing Problem with Time Windows

1800-1930 Dinner

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Saturday June 14

0900-1000	**Aggregation and Decomposition**	**(Chair: Christian Prins)**
0900-0930	Eivind Nilssen	Aggregation based on road topologies for large scale VRPs
0930-1000	Christian Prins	The route-first cluster-second principle in vehicle routing

1000-1030 Coffee

1030-1130	**Supporting Methods**	**(Chair: Arne Løkketangen)**
1030-1100	Oddvar Kloster	Calculating time-dependent travel times for VRPs
1100-1130	Arne Løkketangen	The use of distance measures in routing problems

1130-1230	**Panel and Closure**

1230-1330 Lunch

The Consistent Vehicle Routing Problem

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Abstract

In the small-package shipping industry (as in other industries), companies try to differentiate themselves by providing high levels of customer service. This can be accomplished in several ways including on-line tracking of packages, ensuring on-time delivery, and offering residential pick ups. Some companies want their drivers to develop relationships with customers on a route and would like the same drivers to visit the same customers at roughly the same time on each day that the customers need service. These service requirements together with traditional constraints on vehicle capacity and route length define a variant of the classical capacitated vehicle routing problem (VRP) that we call the Consistent VRP (ConVRP).

In this paper, we formulate the problem as a mixed integer program (MIP) and develop an algorithm to solve the ConVRP that is based on the record-to-record travel algorithm. We compare the performance of our algorithm to the optimal MIP solutions for a set of small problems and then apply our algorithm to five simulated data sets with 1,000 customers and a real-world data set with more than 3,700 customers. The solutions produced by our algorithm on all problem sets do a very good job of meeting customer service objectives with routes that have a low total travel time.

Keywords: Vehicle routing problem; heuristics; customer service

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Vehicle Routing and the Green Agenda

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The main objective of logistics systems has been to co-ordinate plan operations in a way that meets customer requirements at minimum cost. In the past this cost has been defined in purely monetary terms. As concern for the environment rises, organisations wish to take more account of the external costs of logistics associated mainly with climate change, air pollution, noise, vibration and accidents.

As part of a research programme in the U.K. on green logistics in general (www.greenlogistics.org), we are studying what contribution might be made to environmental objectives through vehicle routing models that do not solely focus on economic objectives.

Current vehicle routing and scheduling software is designed to produce schedules for freight vehicles to minimise the relevant economic costs to the logistics service provider. Typically these are based on numbers of vehicles and drivers required and the distance travelled. Although the software may allow different speeds for vehicles on different types of roads, this is a rough approximation that does not take into account the different speeds on different roads at different times of day and different days of the week. This results in schedules where freight vehicles spend time in congested traffic, contributing to the congestion and associated environmental costs. There are also economic and social costs due to missed delivery time windows and overtime costs when routes take longer than planned.

Transit time variations on different routes that are due to congestion and features such as long-term road works can be predicted from past experience. Data in the form of a Road Timetable™ database are now available through companies such as ITIS Holdings plc to provide the information that shows how long it will take to travel along different roads at different times of day and different days of the week.

Using data from ITIS Holdings plc, we are developing a prototype vehicle routing and scheduling system to take this information into account and to plan schedules for different types of distribution operations that minimise the time-based costs.

The paper describes some of the technical issues involved in developing the software to meet this requirement.

Results are presented using data from a case study involving distribution of goods by an electrical wholesaler in the south west of England that indicate potential benefits from this approach.

Synchronized vehicle routing

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Extended abstract

Combined vehicle routing and scheduling with time windows arises in many applications and there is an extensive and wide research literature on Operations Research models and methods, both exact and heuristic. Temporal constraints within a route for one vehicle frequently occur in well known problems such as the dial-a-ride and the pickup and delivery problems. However, the problem of vehicle dependencies is given much less attention in the literature. A typical application is when two vehicles must meet at a point at the same time or when a vehicle cannot pick up a load until another vehicle has delivered the same load. We will present a general mathematical programming model for the combined vehicle routing and scheduling with time windows and additional temporal constraints. The temporal constraints introduced allow for imposing pairwise temporal precedence and pairwise synchronization between customer visits, independently of the vehicles.

Given a fleet of vehicles available in a depot and a set of customers to be serviced within their respective prescribed time windows, the objective for the vehicle routing and scheduling problem (VRSP-TW) is for example, to minimize the total traveling time. The VRSP with a single vehicle and precedence constraints is commonly seen as a traveling salesman problem with precedence constraints. In the pickup and delivery and the dial-a-ride problems, the precedence constraints are limited to precedence within a route for a single vehicle. A related problem is the job shop scheduling problem (JSP), where each job is defined by a set of ordered activities and each activity is normally to be executed on one predefined resource. All activities for one job are not bound to one resource and the precedence constraints therefore span over multiple resources, as opposed to the pickup and delivery and the dial-a-ride problems. Beck et al. (2003) study the differences between VRP and JSP and apply both vehicle routing and scheduling techniques to VRPs. In their study, they include vehicle independent precedence constraints to the VRP and observe that the routing techniques they use have difficulties in finding feasible solutions, while the scheduling techniques find feasible solutions to all the studied problem instances.

In the combined vehicle and crew scheduling problem for urban mass transit systems, drivers are allowed to change bus in so called relief points. Commonly, as seen in Haase et al. (2001) and the work of Freling et al. (2003), the arrival time at a relief point is defined by a timetable and therefore the synchronized arrival of bus drivers is implicitly considered. In the homecare scheduling problem presented in Eveborn et al. (2006), there is a required synchronization of staff visits to customers (such as elderly people). The model for the periodic routing and airline fleet assignment problem, presented in the paper by Ioachim et al. (1999), has temporal constraints that define the same departure time for pairs of flights, which is a set of synchronization constraints in the sense that we use in this paper. For their problem they develop a multi-commodity flow formulation and a solution method based on a side constrained set partitioning reformulation, which they solve with column generation in a branch-and-bound framework. The solution process is further developed in Belanger et al. (2006) where characteristics of the subproblem are used.

In this paper we want to emphasize the importance of the temporal synchronization and precedence constraints found in several real world applications. For this purpose, we suggest a straight-forward model of the VRSP-TW and extend it with the introduced constraints. The proposed model is a generalization of the VRSP-TW. Using standard VRSP-TW some strict simplification of the problem must be enforced to handle the synchronization constraints. A standard approach is to put a strict limit on the time windows providing a simplified VRP problem. A model that considers some synchronization constraints for an airline fleet assignment and routing is given in Ioachim et al. (1999). Our model however, is more general and is based on an extension of a traditional VRP model. We also demonstrate through the computational experiments that our proposed model is not significantly harder to solve compared to a VRSP-TW model without synchronization constraints. We also demonstrate the potential improvements in handling the constraints explicitly in the model. We propose an optimization based heuristic that finds high quality solutions within specific time limits. We do not suggest that this model should be used directly to solve all applications. It does however, describe the temporal constraints clearly. It can also be used as a basis for formulating and developing more application oriented models and solution methods. We also present a branch and price algorithm which is tested on a set of test problems with good results.

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Solving the Single-Vehicle Routing Problem with Stochastic Demands

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The Single-Vehicle Routing Problem with Stochastic Demands (SVRPSD) consists in finding a tour for a single capacitated vehicle delivering goods to a set of customers with stochastic demands. A key feature of the problem is that whenever the demand of a customer is found to exceed the remaining stock on the vehicle, it must replenish its stock by going back to the depot. These trips back to the depot increase the length of the route effectively performed by the vehicle. The objective in the SVRPSD is to find the route that yields the lowest expected total cost when these trips to the depot are considered.

In this talk, we will present both an exact and a heuristic solution methods for the SVRPSD. Both methods rely heavily on concepts of the *local branching* approach proposed by Fischetti and Lodi to tackle mixed integer programs effectively. Computational results on a set of small to fairly large benchmark instances will be reported and discussed.

(Joint work with Walter Rei and Patrick Soriano)

The Double TSP with MultipleStacks - Heuristic Solution Approaches

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Abstract:
The talk introduces the Double Travelling Salesman Problem with Multiple Stacks. The Double TSP with Multiple Stacks is dealing with the determination of the shortest route performing pickups and deliveries in two separated networks (one for pickups and one for deliveries) using only one container. The container is loaded and unloaded from the end of the container. Repacking is not allowed. Instead each item can be positioned in one of several "rows" in the container such that each row can be considered a LIFO (last in, first out) stack. No mutual constraints exist between the rows. In a typical instance the container has three rows each having up to 11 items. Four different solution methods based on metaheuristics are presented and some computational results are given along with lower bounds on the objective value.

Vehicle routing problems with alternative paths

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The class of vehicle routing problems involves the optimization of freight or passenger transportation activities. These problems are generally treated via the representation of the road network as a weighted complete graph. Each arc of the graph represents the shortest route for a possible origin-destination connection. Several attributes can be defined for one arc (travel time, travel cost ...), but the shortest route modelled by this arc is computed according to a single criterion, generally travel time. Consequently, some alternative routes proposing a different compromise between the attributes of the arcs are discarded from the solution space. We propose to consider these alternative routes and to evaluate their impact on solution algorithms and solution values through a multigraph representation of the road network. We point out the difficulties brought by this representation for general vehicle routing problems and we propose a dynamic programming solution method for the fixed sequence arc selection problem (FSASP). In the context of an on-demand transportation (ODT) problem, we propose a simple insertion algorithm based on iterative FSASP solving and a branch-and-price exact method. Computational experiments on modified instances from the litterature and on realistic data issued from an ODT system in the French Doubs Central area underline the cost savings brought by the proposed methods using the multigraph model.

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New hybrid heuristics for a location-routing problem

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As pointed out by Nagy and Salhi in their recent survey [1], many variants of the location routing problem (LRP) are addressed in the literature. Generally speaking the LRP consists of determining locations for depots from which customers are served on routes with the objective of minimizing the overall cost. In this talk we consider the capacitated location-routing problem (CLRP) which is defined as follows. Let G = (X, E) be an undirected graph where X is the vertex set and E the edge set. $X = V \cup$ W is composed of m vertices in V associated with potential location sites and of n vertices in W associated with customers. A cost matrix is defined on E and a fixed opening cost is associated with each vertex of V. Each customer i must be served a demand d_i from a depot. The total demand served from one depot must not exceed the depot capacity $\overline{Q}$. To deliver the demand, a fleet of vehicles is available and with each vehicle is associated a maximal capacity Q. A solution of the CLRP is a set of location sites for the depots and a collection of routes where: (i) each customer is visited only once; (ii) the total demand for each route is at most Q; and (iii) the total demand delivered from each depot is at most $\overline{Q}$. The CLRP aims to determine a minimal total cost solution. The total cost is the sum of the opening costs and of the routing costs.

In this talk we consider the following decomposition of the CLRP. Let us first consider that the depot locations are fixed. Then the CLRP reduces to the Multi-Depot Vehicle Routing Problem (MDVRP). On the other side if customers are a priori clustered into groups with total demands less than Q, the CLRP is the Capacitated Plant Location Problem (CPLP). Thus a generic algorithmic scheme can be devised in which MDVRPs and CPLPs are solved alternatively. Their solutions provide respectively sets of customers associated with routes and sets of opened depots which can be used in the solution of the counterpart problem. In our approach CPLPs are solved using an exact algorithm while good solutions for MDVRPs are obtained thanks to a tabu search heuristic. Based on this general scheme different hybrid heuristics are described and compared on a classical test bed. Computational results obtained by the best heuristic compare favorably with the heuristics previously described in the literature [2].

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[2] C. Prins, C. Prodhon, A. Ruiz, P., R. Wolfler Calvo (2007), Solving the Capacitated Location-Routing Problem by a Cooperative Lagrangean Relaxation-Granular Tabu Search Heuristic, *Transportation Science* 41, 470-483.

Livestock collection

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The Livestock Collection Problem (LCP) is a rich, real-world, routing problem where several constraint sets at the route level are combined with global inventory constraints. The problem is taken from the Norwegian meat industry, and deals with transportation of live animals from farms to a slaughterhouse.

Our version of the LCP is based on the well-known Vehicle Routing Problem (VRP). Many of the standard extensions to the basic model are added, such as a heterogeneous vehicle fleet, duration constraints and precedence constraints. Constraints on how animals of different species, genders and sizes may be mixed in the same compartment on board the same vehicle also have to be added. These constraints on mixing of animals lead to a situation where the capacity of each vehicle depends on the visiting order of the farms on each tour, meaning that one also gets a packing or loading problem to handle.

In addition to the routing constraints, global constraints on the number of animals kept in inventory has to be added. The lairage at the slaughterhouse has a limited capacity, and the animals cannot stay there for more than one day. The lairage serves as a temporary storage between farmer and slaughtering, and there must always be enough animals in the lairage to keep the slaughtering go as planned.

A mathematical model for our version the LCP can be formulated in about 40 lines, and in addition to being large, this model includes a lot of binary variables and non-linear constraints that make it impossible to solve exactly for instances of realistic size. We have developed a Tabu Search based heuristic for the LCP, in addition we have used a column generation approach to solve small instances to optimality. Results from both methods are presented.

In order to make practical use of the results from the project, there are plans to implement the main results in an industrial solver.

Vehicle routing methodologies to support costing and pricing decisions

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Although Vehicle Routing methologies have been used to tackle different problems at the operational, tactical and to a lesser extent strategic level of decision-making in distribution logistics, their use in supporting costing and pricing decisions has been limited.

Routing problems have been previously used in combination with cooperative game theory in certain cost-allocation games as the travelling salesman game (e.g. Engevall et al., 1998), cost allocation in the Chinese postman problem (e.g. Hamers et al., 1999) and cost allocation in the vehicle routing problem (e.g. Engevall et al., 2004) but their use has been limited to relatively small cases. Vehicle routing models have been used to develop incentives to influence consumer behavior to reduce delivery costs for home delivery services, e.g. by Campbell and Savelsbergh (2005, 2006). Recently Confessore et al. (2008 have developed an approach to estimate routing costs based on time window size to develop a pricing structure to stimulate customers to be more flexible with respect to their delivery. In this paper we present another approach involving local search operators to estimate the incremental cost of customers and use these cost estimates to see whether they can be used to develop a pricing structure based on a limited number of cost drivers.

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A multi-objective distribution problem for parcel delivery at TNT

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With almost 160.000 employees worldwide and a 2006 turnover of over 10 billion US$, TNT is one of the largest courier services companies in the world. Its main operations consist of collecting parcels from customers, and redistributing these parcels to a destination indicated by the customer. In this talk, we discuss several opportunities for operations research, and especially vehicle routing, to assist in these complex operations. We also discuss a heuristic approach that we developed for a multi-objective routing problem at TNT.

The way in which TNT works is as follows. Customers call to demand the pickup of a parcel. The parcel is pickup later that day (or the following day, if pickup that day is not possible), and brought to the distribution center. There, it is sorted and loaded into bins (containers). These containers usually contain the orders to be delivered to a geographically restricted region. If possible, these regions are defined by postal code, for easy sorting. When orders have been loaded into containers, the assignment of containers to trucks is determined. Each truck may contain a fixed number of containers. Pre-sorting the items in containers has the additional advantage that late-arriving parcels can be added to the correct container at the last minute. Of course, care is taken that containers on a specific truck correspond to geographical regions that are in close proximity, to minimize unproductive travel of the trucks. When all containers have been loaded, the trucks leave the depot and visit each geographical region corresponding to a container. In each geographical region, all delivery points are visited in milk-runs.

If we focus on the *distribution* side of the operations, i.e. after the parcel has been dropped of at the hub, several potential optimization problems arise:

1. Determining the regions for delivery (containers).
2. Determining the assignment of regions (containers) to trucks.
3. Determining the order in which regions should be visited.
4. Determining the milk-runs per region.

In this talk, we focus on problems 2 and 3, as this was seen by TNT to be the most urgent. Problem 1 is a so-called *districting* problem, in which the aim is to partition the set of customers into subsets so that certain criteria are satisfied. This problem is a tactical, rather than an operational problem, because TNT does not want these zones to change from day to day. The main reasons for this are that it should be easy to sort the packages into containers corresponding to a region (which is why postal codes are mostly used), and that drivers should be able to become acquainted with the geographical layout of a certain zone. Determining the zones on a day-to-day basis, i.e. as an operational problem, is not an option.

Problem 4, determining the milk runs in each region, is done by the driver, who is mostly familiar with the characteristics of a certain region, and with the peculiarities of different customers (e.g. opening hours, ...). Although decision support systems integrated in the trucks are envisaged to help solve this problem, drivers should still be given some discretion in determining their own delivery pattern.

In this talk, we discuss how problems 2 and 3 can be solved in an integrated way. For each region, TNT calculates an average (expected) amount of work. The real time needed to completely finish all deliveries in a region may deviate from this due to a multitude of factors (e.g. traffic conditions, customer unavailability, ...). A driving time between each pair of regions, corresponding to the time needed to drive from the boundary of a region to another one, is also calculated. Total travel time for a given truck is equal to the travel time within each region plus the travel times between regions. It is not difficult to see that the problem to minimize total travel time is simply a capacitated vehicle routing problem (CVRP).

From discussions with TNT, three different objectives were identified:

1. The total travel cost (distance or time) of all trucks should be minimized.
2. The routes should be *balanced*, i.e. the difference in route cost between the shortest and the longest routes should be minimized.
3. The routes should not change too much over time.

Objective 3 was considered to be very important by TNT, because the familiarity of a driver with a certain region has many advantages. Moreover, some companies require TNT to visit them with the same driver each day, e.g. because they want to entrust the driver with a key to their company.

In this talk, we discuss a tool that we developed to support these operational decisions at TNT. The outcome of the tool is a limited set of alternative solutions, each with a high performance on each of the three criteria. The tool uses specifically developed neighborhood structures, combined with update rules for each of the three criteria, in a metaheuristic framework. Results of the tool will be discussed.

Routing problems in maritime logistics

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Maritime logistics is a rich source of new routing problems with variations and extensions to the classical routing problems. In the first part of the talk we will highlight two variations of the pickup and delivery problem (PDP) that arise in maritime transportation problems. The first variation is a PDP where pickups and deliveries are independent, i.e. a pickup can be counterpart to any matching delivery. These problems can arise in a spot market where the transporter buys product from different suppliers and sells it to consumers. The second variation involves PDPs with a set of pickup and delivery ports. For each port it is specified a minimum and maximum number of visits. The problem is to find a set of routes of minium cost that alternates between visits at pickup and delivery ports, with the number of visits being in the given interval. This problem can be seen as a simplified version of the Inventory Routing Problem, especially if we consider the generalization to multiple periods.

In the second part we will give a presentation of a general software library to solve maritime routing problems including the above mentioned problems as special cases. The library solves problem involving pickup and delivery orders in combination with inventory routing. In addition we handle a rich set of problem extensions including tank allocation and tank cleaning, and contractual requirements with volume limit constraints and destination restrictions. We present an overview of a construction algorithm used to solve the problem, and its combination with a guiding heuristic based on a genetic algorithm.

(Joint work with Oddvar Kloster, SINTEF ICT)

The LNG Inventory Routing Problem with Pick-up Contracts

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Abstract

We will describe a combined inventory management and routing problem arising in the LNG business. The LNG supply chain is long and complex, stretching from exploration and extraction, via liquefaction, transportation and regasification to distribution to end customers. In this presentation we will focus on the part of the chain from the liquefaction plants to the regasification terminals. The actor purchases the liquefied gas at the liquefaction plants and delivers it to regasification terminals. The purchases are controlled by contract having upper and lower limits on the amount of LNG that can be loaded. The contracts also have origin-destination clauses that limit to which regasification terminals some of the LNG must be delivered. At the regasification terminals, upper and lower limits on inventory levels have to be obeyed.

This problem is an extension of the LNG inventory routing problem, and we will present and discuss a path-based model and a solution method based on branch and price.

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Optimizing a Maritime Split Pickup and Split Delivery Problem

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Abstract

We discuss alternative formulations of the multi commodity split pickup and split delivery problem without predefined pairing of locations. Pickup and delivery quantities in each location can be less or greater than vehicle capacity. All quantities can be split between a non-specified number of vehicles. Some commodities have only one pickup or delivery location, while other commodities can have several locations both for pickup and delivery. Only commodities with only one pickup point and one delivery location are paired. We assume that we have available a heterogeneous fleet of vehicles (with emphasis on ships). Each vehicle can carry several commodities simultaneously. We plan to report computational results for small test cases solved by different approaches.

When feasibility of routes is difficult to determine: an example from maritime bulk shipping

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In maritime bulk shipping, the major decision is to plan vessel routes in order to service requests for the transportation of bulk cargos. However, in many real world applications, the subproblem of deciding whether a given vessel route is feasible with respect to stowage is of importance. There are various constraints that could possibly render a route infeasible, such as the physical capacity of the tanks onboard the vessel, specific regulations for transportation of hazardous materials, or requirements for the stability and strength of the vessel. A mixed integer programming model is formulated for this problem, and it can be shown that the problem is NP-hard even when some of the suggested constraints are relaxed.

Even though it is computationally intractable to determining whether a given route is feasible, this problem must potentially be solved repeatedly when designing the vessel routes. A study is presented in order to determine whether standard MIP-solvers can be used to this end, and specially tailored heuristics are discussed as an alternative.

(Joint work with Kjetil Fagerholt and Vinícius Amaral Armentano.)

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Multiperiodic VRP models and hybrid solution techniques for closed loops-reverse logistics

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More and more manufacturers are confronted with the problem of "Reverse Logistics" which, as defined by the *"American Reverse Logistics Executive Council"* [Rogers and Tibben-Lembke, 1999], is: *"The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or of proper disposal"*. Companies have different reasons to design a reverse logistic system: legislation, commercial advantage, environmental issues, etc... In recent years, a significant amount of work has been focused on the design and optimization of logistic systems with reverse flows [Bostel et al., 2005].

In this paper, we consider generic problems for the multiperiodic planning and optimization of both routing activities and inventory management policies in a two level distribution network composed of a central warehouse and *n* retail stores. Distributed products sold by the stores are transported on returnable pallets. Two types of reverse flows have to be considered: for the return of unloaded pallets from the stores to the warehouses and for the return of products brought back to the stores by consumers or unsold. In order to satisfy the customer demands at the stores and replenish the inventories as well as balance the availability of pallets, pick up and delivery tours are organized over the planning period between the central warehouse and the stores using a homogeneous fleet of vehicles. Store servicing must meet time windows and they may be visited by several vehicles during one day. The purpose of the planning and optimization of the system is to determine the days of visits to each store as well as the quantities delivered or picked-up of the products and pallets. The aim of this problem is to satisfy the customer demands at the stores while minimizing the routing and storage costs. In order to determine the best management policies, we consider two cases: "just in time" delivery where the procurement to the stores must coincide with their customers demands on the same day, or "inventory" where we allow the possibility of delivering the products to the stores in advance in order to better optimize the shipments and inventories.

In order to solve these problems, we have developed both heuristic solution techniques and a column generation approach. As a basis for our heuristic solution techniques, we use the GRASP (Greedy Randomized Adaptive Search Procedure) metaheuristic [1989]. In a first phase we have adapted the classical construction method "Best Insertion", with greedy, random and adaptative features. In a second phase, we use two versions: one using a classical local search and one using a hybrid local search, and compare them. For the classical local search we use different known methods [Laporte and Semet, 2001]), in specific sequences for the “just in time case” and for the “inventory case”. For the hybrid local search, we adapted the Large Neighbourhood Search (LNS) method originally proposed by Shaw [1998]. This technique explores the neighbourhood of the solution by selecting a number of visits to be removed from the routing plan and reinserting them later. To find the best possible insertion for the nodes removed and determine a good planning on the new routes, we use the Limited Discrepancy Search (LDS) proposed by Harvey and Ginsberg [1995]. For all these methods, we combine improvement methods on each route separately (intra-route) and on several routes simultaneously (inter-route).

As a solution procedure based on exact methods, we consider a set partitioning formulation of the problems. Starting feasible solutions are generated using the previously described heuristics. A column generation procedure [Desaulniers et al., 2004] has been developed in order to solve the restricted Master problems. Several solution techniques for the resource constraint shortest path subproblems have been implemented and compared, using dynamic programming, tabu search, and constraint programming [Rousseau et al, 2002]. In order to find feasible solutions to the global problems, we restrict ourselves to a branch and bound procedure.

A set of 1848 instances has been generated based on the classical Solomon's testbed [1987] for the VRPTW with 25 sites. The results obtained by the GRASP approach depend on the resolution approach and the instances. With the column generation approach, we have limited the tests to 204 instances with 5 or 6 sites. Using the branch and bound procedure, we could obtain integer solutions for all cases of the "just in time" policy, but only for 25% of the cases of the "inventory" policy. The obtained results will be presented and compared, showing the relevancy of our models for the comparison of different logistics policies as well as for the performance evaluation of the different solution methods, depending on the characteristics of the instances.

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Solving Real-World Vehicle Scheduling and Routing Problems

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The classical capacitated vehicle routing problem forms the core of many real-world applications, e.g. in transportation management systems. However, real-world scenarios are typically more complex since they involve multiple objective functions, many constraints and decisions to be made. We sketch the most important features of the *vehicle scheduling and routing problem* (VSRP), for which an optimization algorithm is offered in SAP's supply chain management solution, a commercial software that allows to plan and optimize the whole supply chain. The VSRP is used by our customers to model and solve their vehicle scheduling scenarios. Each customer's transportation business has special requirements that are mapped into a certain family of VSRP instances sharing structural similarities. As scenarios of different customers may differ significantly, the VSRP covers a heterogeneous set of instances. We present an outline for our solution algorithm and give an overview of selected real-world VSRP scenarios from SAP's customer base.

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A Process Oriented Modelling Concept for Rich Vehicle Routing Problems

The globalisation of the economy leads to a rapidly growing exchange of goods on our planet. Limited commodities and transportation resources, high planning complexity and the increasing cost pressure through the strong competition between logistics service providers make it essential to use Computer-aided systems for the planning of the transports. An important subtask in this context is the operational planning of trucks or other specialized transportation vehicles. These optimization tasks are called Vehicle Routing Problems (VRP). Over 1000 papers about a huge variety of Vehicle Routing Problems indicate the practical and theoretical importance of this NP-hard optimization problem. Therefore, many specific solvers for different Vehicle Routing Problems can be found in the literature. The drawback is that most of these solvers are specialized on limited problem types and it needs a lot of effort to adapt them to modified problems. Additionally, most real world problems are often much more complex than the idealized problems out of literature and they also change over time. To face this issue, we present an integrated modelling and optimization concept for solving complex and practical relevant Rich Vehicle Routing Problems. Its modular and process oriented structure, a library of VRP related neighbourhoods and algorithms, and a graphical user interface give the user both reusable components and high flexibility for rapid prototyping of complex Vehicle Routing Problems. An empirical investigation on standard benchmark problems for several VRP types shows that this flexible approach can also produce high quality solutions in reasonable time.

Industrial Aspects and Literature Survey: Fleet Composition and Routing

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The purpose of this talk is to describe industrial aspects of combined fleet composition and routing in maritime and road-based transportation, and to present the current status of research in the form of a comprehensive literature review. With a backdrop of industrial aspects, a categorized survey of relevant literature since the first published papers in the 1950's is given. First, the literature review discusses some early seminal and application-oriented papers, presents a classification of problems, and then focuses on a basic definition of combined fleet composition and routing: the fleet size and mix vehicle routing problem. Three basic mathematical formulations from the literature are presented and compared. Further, the literature of extended and related problems is described and categorized. Surveys of application oriented research in road-based and maritime transportation conclude the review. Finally, we contrast the literature with aspects of industrial applications from a critical, but constructive stance. Major issues for future work are suggested.

(Joint work with Henrik Andersson, Marielle Christiansen, Geir Hasle and Arne Løkketangen)

A Powerful Route Minimization Heuristic for the Vehicle Routing Problem with Time Windows

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The vehicle routing problem with time windows (VRPTW) is one of the most important and widely studied problems in the operations research. The objective of the VRPTW is to minimize the number of routes (primary objective) and, in case of ties, the total travel distance (secondary objective). Given the hierarchical objective, most of the recent and best heuristics for the VRPTW use a two-stage approach where the number of routes is minimized in the first stage and the total distance is then minimized in the second stage. It has also been shown that minimizing the number of routes is sometimes the most time consuming and challenging part of solving VRPTWs.

In this talk, we will present an efficient heuristic method for reducing the number of routes in VRPTWs. The suggested method is based on the idea of the ejection pool that is combined here with the tabu search framework to determine the ejections. Moreover, we incorporate a powerful insertion procedure that accepts temporal infeasible insertions, followed by an attempt to restore the feasibility.

The suggested method was tested on the 300 well-known large-scale benchmark problems of Gehring and Homberger. The computational results demonstrate that the proposed method outperforms the best heuristics that have been applied to these benchmarks in terms of the number of routes. It found all best-known and 18 new best-known solutions, resulting in 10290 of the cumulative number of routes.

A route minimization heuristic for rich Vehicle Routing Problems

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Abstract We are investigating methods for route minimization in a rich VRP solver. Experiments on standard VRPTW benchmarks have shown that relatively simple tour depletion procedures leave a significant gap relative to the competition. The successful work on the VRPTW by Bent and Van Hentenryck [1] has inspired us to develop improvements and extensions to their hierarchical tour reduction objective. The objective is applied in a separate tour reduction phase after construction. In experiments, we have observed that switching between alternative tour reduction objectives gives good diversification and faster convergence to a good result, regardless of the quality of the initial solution. Experiments on the 400 customer VRPTW instances of Gehring and Homberger show that results are highly competitive.

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Vehicle routing methodologies to support costing and pricing decisions

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Although Vehicle Routing methologies have been used to tackle different problems at the operational, tactical and to a lesser extent strategic level of decision-making in distribution logistics, their use in supporting costing and pricing decisions has been limited.

Routing problems have been previously used in combination with cooperative game theory in certain cost-allocation games as the travelling salesman game (e.g. Engevall et al., 1998), cost allocation in the Chinese postman problem (e.g. Hamers et al., 1999) and cost allocation in the vehicle routing problem (e.g. Engevall et al., 2004) but their use has been limited to relatively small cases. Vehicle routing models have been used to develop incentives to influence consumer behavior to reduce delivery costs for home delivery services, e.g. by Campbell and Savelsbergh (2005, 2006). Recently Confessore et al. (2008 have developed an approach to estimate routing costs based on time window size to develop a pricing structure to stimulate customers to be more flexible with respect to their delivery. In this paper we present another approach involving local search operators to estimate the incremental cost of customers and use these cost estimates to see whether they can be used to develop a pricing structure based on a limited number of cost drivers.

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Aggregation based on road topologies for large scale VRPs

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In large scale vehicle routing problems, such as waste collection or distribution of media products, the large number of customers are challenging for transportation planning tools. The topology distance table becomes too large for the available memory, and search operators may become exceedingly slow when routes contain a large number of customers.

We present work which aggregates customers in real-world VRPs based on the road topology. Customer locations are snapped to their nearest road link in the topology. Customers sharing the same road link are aggregated, up to some upper limit on demand size and/or service time. The location of the *aggregate customer* is represented by an edge which may be traversed in both directions. The demand size of the aggregated customer is simply the sum of the customer demands forming the aggregate, whereas the service time of the aggregate also takes into account the road topology travel time between the customers. The service time may therefore depend on the direction of travel the aggregate is being serviced in a given plan. Other attributes of aggregate customers are similarly set and problem constraints are updated, based on the attributes of the original rich VRP. The new VRP, having much fewer customers, is optimized with our SPIDER solver engine, and the resulting plan to the aggregate VRP is transferred back to a plan for the original VRP.

The route-first cluster-second principle in vehicle routing

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Some classical heuristics for the VRP are based on the cluster-first route-second principle, for instance the sweep heuristic from Gillett and Miller (1974). In contrast, the route-first cluster-second principle has been seldom used. Beasley (1983) suggested some heuristics based on this principle, but without numerical results.

The talk will show that the route-first cluster-second principle can lead to effective heuristics and metaheuristics. We started using this principle successfully to evaluate chromosomes encoded as giant tours (or TSP tours, i.e., without trip delimiters), in a memetic algorithm (MA) for the VRP (2004). The procedure called *Split* builds an acyclic auxiliary digraph, in which each arc represents a feasible subsequence (trip) of the giant tour. The optimal splitting, subject to the sequence, corresponds to a shortest path in this graph. This idea is interesting since there is no loss of information: a VRP solution can be deduced optimally from each giant tour and it is easy to see that there exists one optimal giant tour (one giving an optimal VRP solution after splitting). Moreover, the MA explores a much smaller solution space.

The principle can be transposed to arc routing problems like the Capacitated Arc Routing Problem or CARP (2004) and the Mixed CARP or MCARP (2006). In general, many constraints met in practice concern the trip level: trips which do not satisfy such constraints are not included in the auxiliary graph but the shortest path computation is not affected. For instance, we obtained excellent results by developing ad hoc versions of *Split* in MAs for the Split Delivery VRP (2007), the CARP with Time Windows (2007), the VRP with Time Windows (to appear) and the Vehicle Fleet Mix Problem or VFMP (2006).

In 2006, we studied a more complex case for the periodic CARP or PCARP, motivated by municipal waste collection. The hierarchic objective function includes the number of required vehicles and the total cost of the routes over the horizon. We designed an MA and a scatter search (2006) which can be easily transposed to the periodic VRP. Each solution is encoded as a sequence of sub-chromosomes (one per day), and each sub-chromosome as a giant tour, like in the MA for the CARP. It is still possible to split such chromosomes optimally and in polynomial time. The Heterogeneous Fleet VRP (HFVRP) is even more involved because it raises a resource-constrained shortest path problem in the auxiliary graph. However, we developed a pseudo-polynomial version of *Split* which is fast enough in practice (2006).

Applications of the splitting principle are not limited to population-based metaheuristics. Recently, we designed for the VRP an Iterated Local Search (ILS) which alternates between giant tours and detailed VRP solutions. This method (forthcoming) becomes the second most effective metaheuristic for the VRP, just after the Active Guided Evolutionary Strategy (AGES) of Mester and Bräysy (2005).

Only recently, we compared simple splitting heuristics with traditional constructive heuristics for the VRP, to bring the numerical evaluation missing in Beasley (1983). In general, splitting an optimal TSP solution does not give an optimal VRP solution. Surprising results (forthcoming in IJPR) are obtained by applying *Split* to a set of giant tours generated by a randomized TSP heuristic.

Calculating time-dependent travel times for VRPs

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In many transportation problems, the fact that travel times vary depending on when one travels is an important aspect. As standard algorithms for calculating time-dependent travel times in road networks are too slow to handle the large number of requests made in a VRP solver, specialized algorithms are needed.
We present a topology module for VRPs with time-dependent travel times. The model is based on the concept of a *cost function* that captures all relevant information about travel along one or more road links or paths. Cost functions form a closed semiring, which makes them suitable for use in standard shortest path algorithms. However, they may be computationally expensive. We therefore focus on reducing the effective size of the road network, by arranging it in a hierarchy of regions. For each region, we precompute the *thoroughfare*, which contains the road links in all shortest paths *through* the region. In a computation, the required thoroughfares are stitched together to produce a small network that yields the correct result. We also introduce approximations in the cost function calculations in order to manage their complexity.
A demonstration on synthetic data is included.

The use of distance measures in routing problems

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When solving problems in the real world using optimization tools, the model solved by the tools is often only an approximation of the underlying, real, problem. Usually average values are used instead of underlying stochastic values, or some parts are simplified in order to be able to find solutions. In these circumstances, a decision maker (DM) might be more interested in a set of different, good solutions, rather than just the optimal solution as produced using the model. On the other hand, the same DM will only be interested in seeing a few of the solutions, and not the plethora of solutions often produced by modern search techniques. There is thus a need to distinguish between good solutions, based on some other concept than quality alone (i.e. objective function value). We develop a distance measure of the type proposed in the Psychology literature by Tversky for the class of VRP problems. We base our difference on the underlying structure of solutions, also including attributes of the problem that are not in the problem model.

In addition to identifying diverse solutions, there is also a need for identifying similar solutions. When the solutions are plans are produced using a rolling horizon principle, the solution is updated whenever new information becomes available, or on a regular basis. In any case, the planner have often already made commitments w.r.t. the execution of the plan represented by the solution, at least for the near future. Therefore, the planner is interested in seeing a set of high quality solutions that are close to the current (base-line) schedule in the near future, and diverse from each other in more distant time.

Our measures have been tested on a set of real-life problems from land and sea, and it provides valuable decision support flexibility for the planner.

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