Heuristic Routing Software for Planning of Combined Road Transport with Swap Bodies: A Practical Case

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Abstract
The rising number of loading devices called swap bodies in road transport has created new opportunities for carriers and novel challenges for researchers in vehicle routing synchronization. Nevertheless, there are few vehicle routing models in literature that integrate swap bodies for combined road transport and there is no known best practice in the industry to handle these opportunities. In this paper we aim to examine to which extent Information Systems and Operations Research can help to provide solutions for this new planning problem and evaluate the potential of vehicle routing under consideration of swap bodies regarding a real world case of a major carrier. We develop a routing heuristic and prototype software to support routing considering loading options with swap bodies. The software is tested with real world data from the cooperating industry partner. We observe significant reductions in costs, total driven kilometers and operating times. Thus, we demonstrate the importance to integrate swap bodies in vehicle routing models for road transport. Furthermore, the developed software can be a basis for future work on exact planning models.

1 Introduction
Growing competition in transport has increased the importance of economic and ecological customer requirements in the industry. Swap body containers were introduced in the end of the 60s in Germany. Swap bodies are loading devices that enable truck drivers to load and unload containers without further equipment at flexible locations (change points or transshipment points), which could, e.g., be service areas alongside highways. Thus, more routes can be combined, leading to fewer total driven kilometers, reduced costs and less emissions. New improvement potential appears as this new situation
is taken into consideration in the route planning process. However, synchronization in vehicle routing is an emerging field in literature [5][6] and there are few models that explicitly integrate swap bodies for combined road transport [12]. Also, a best practice in the industry remains to be developed.

Swap bodies are a special type of containers. Containers are independent of the transport vehicle and can be separated from those. A special characteristic of swap bodies is that they have stilts on the side of the containers. Therefore, they can be stored at any place of the tour [11]. The process of the pickup of a container is shown in Figure 1.

![Figure 1: Process of swap body container loading](image1)

The container first stands on the stilts. Air is released from the suspension of the truck. The truck can now drive below the container. Then the truck puts air again in the suspension and picks up the container. The stilts are stored on the side of the container and the truck can drive away with the container.

Swap bodies lead to different requirements and opportunities in transport routing. By looking deeper into the distribution planning within supply chain management, interdependencies of the planning steps can be observed [1]. Operational decisions are made more frequently than decisions that influence strategic or tactical planning. Location planning and parts of the transport fleet planning are long term orientated [9]. A typical task of tactical planning is planning of the transport fleet that contains the optimal selection of the means of carriage. Planning of the routes is part of the operational tasks in the process. In literature the main objectives of the distribution planning are defined as follows:

- Minimization of the number of vehicles
- Minimization of the empty loads
- Maximization of the capacity utilization of the vehicles
- Balancing workload of the vehicles
- Avoiding waiting and downtime of drivers and vehicles
- Minimization of the variable transportation costs

These objectives can appear either complementary or competitively.

In industry, the decision of the location of the hubs is often made by the executive board. The focus of hub location planning is on where the locations are and how they are connected to each other, i.e., how goods are transported between the locations. Decisions need to be made, whether locations are supplied directly or indirectly.
In the practical case of the industry partner all goods are transported from a starting branch (NL) via a hub to another branch (NL). The advantage of this distribution is that long distances are avoided. Furthermore, the flow of goods can be aggregated on such a change point. The biggest disadvantage of this transportation flow is that this method takes more time than direct transportation. The planners in industry have to take care of different requirements. They aim to maximize the capacity of the trucks by planning two swap body containers on a truck with a trailer. The routes should approximately have a length of 650 kilometers. The German legislator gives further restrictions for the periods of rest. The transportation resources are bought from external companies.

Our study is made in cooperation with a German transportation company. Here, we aim to apply methods from Information Systems (IS) and Operations Research (OR) to provide solutions for vehicle routing under consideration of swap bodies. We analyze the requirements in the practical case regarding a routing software solution and an underlying planning model. Accordingly, we develop a routing heuristic and prototype software to support routing considering loading options with swap bodies. We test the software with real world data and analyze costs, total driven kilometers and operating times. Furthermore, we perform a sensitivity analysis assuming different priorities for four different objectives. Finally, we demonstrate how this approach can be integrated in operational, tactical and strategic planning in logistic organizations.

The remainder of this paper is structured as follows. Section 2 provides a brief literature review of transport routing, relevant vehicle routing problems and routing software. Section 3 analyzes modeling and software requirements with respect to the regarded practical case. Section 4 describes the developed heuristic and prototype software and Section 5 provides computational results and sensitivity analysis. Section 6 gives conclusions and further research ideas.

2 Literature Review

This section provides a brief literature review of transport routing with swap bodies, relevant vehicle routing problems in operations research and routing software.

2.1 Vehicle Routing Problems in Operations Research

A vehicle routing model is the basic approach of operations research to model the business of a logistic carrier and similar logistics service providers. This section introduces the relevant specifications of vehicle routing problems.
The vehicle routing problem (VRP) assumes a set of customers that need to be served and a fleet of capacitated vehicles which are responsible for the service [10]. The core objective is to minimize costs, which means minimizing the total distance traveled in order to visit all customers. The VRP is a routing problem for which the existing orders need to be assigned to vehicles. The general aim is to minimize the variable and fixed costs [7]. Additionally, further requirements need to be considered, e.g., time windows, maximum capacities or defaults of the loading order. The VRP can function as a basis to model these requirements.

The VRP with time windows has the additional requirement to deliver the goods to the customer in a defined time window [7]. These time windows can be fixed, i.e., if the orders cannot be in a time window, no solution will be provided [7]. The other opportunity mentioned in the literature are “soft” time windows [1]. In this case disregarding the time windows leads to higher costs of the overall solution.

Other ideas to specify more details lead to the VRP with pickup and delivery (or the Pickup and Delivery Problem). Within related models, goods are not just delivered to a customer but goods are also picked up. This appears, e.g., in the container business, when loaded containers are delivered and empty containers are brought back. In this case the class of Vehicle Routing Problems with Backhauls (VRPB) needs to be considered [13][14]. As in the problems mentioned before, time restrictions can lead to time windows as well. These problems are classified as VRPBs with Time Windows (VRPBTW)[4].

Synchronization and Split VRPs share the assumption that a service can be performed jointly by more than one vehicle. In VRPs it is assumed that each customer has to be served by exactly one vehicle. In the split delivery vehicle routing problem (SDVRP) this single-visit assumption is relaxed and each customer may be served by different vehicles [2][3]. Synchronization VRPs consider different kinds of interdependencies between routes leading to specific requirements of synchronization [6]. Drexl [6] classifies these requirements as task, operation, load, movement and resource synchronization and reviews appropriate modeling and solution approaches. Furthermore, Drexl [5] introduces the Vehicle Routing Problem with trailers and transshipments (VRPTT) that represents a class of vehicle routing problems with multiple synchronization constraints.

Mankowska et al. [12] also describe synchronization problems in vehicle operations and classify synchronization with respect to variable or fixed synchronization points and simultaneous or synchronization with precedence. They formulate a mixed-integer programming model for vehicle routing with fixed synchronization points.

2.2 Routing Software

Solution methods for hard optimization problems as the VRP and its extensions can be divided in exact and heuristic procedures. Exact procedures solve the problem towards optimality, while heuristics do not guarantee to find an optimal solution, but can provide good near-optimal solutions [10].

In 2013 Schipior [17] has analyzed different providers of software with vehicle routing functionality. He shows that the support of consideration of the advantages of swap bodies was not given. The PTV Group offers some modules which the partner uses already, but the modules do not support the restrictions of the swap bodies.
3 Modeling and Software Requirements

The first step towards solving problems is properly modeling them and understanding the requirements. In this section, we analyze requirements of the specific vehicle routing problem and appropriate decision support software.

3.1 VRP with Swap Bodies in the Practical Case of the Industry Partner

For the combined routing problem with swap bodies in the practical case, we have to consider a synchronization type with variable synchronization points and precedence constraints according to the classification of Mankowska et al. [12]. The synchronization points should be defined by planning procedures. Thus, they are not fixed ex ante. Furthermore, we have to assume synchronization requirements for the regarded planning problem as in the class of VRPTTs with operation, load and resource synchronization according to Drexl [5][6]. We consider transshipments (operations) with precedence, swap bodies (load) that need be moved by a vehicle with sufficient capacity and we consider transshipment points as scarce resources that are only available for a restricted number of vehicles and swap bodies. In contrast to the VRPTT, trailers need to be returned to a depot, since they are owned by third-party carriers and for the same reason an unlimited amount of vehicles can be supposed.

Besides that, we need to take specific requirements into account. The tactical planning in the practical case is based on master plans. A master plan is created based on past data and needs to be adjusted every month. The advantage of this planning process is that similar routes that appear regularly do not need to be re-planned. Orders, which do not appear in the master plan, need to be covered with extra tours. The operational planning is done by 25 employees who work seven days a week, 24 hours a day. All swap body containers have a GPS sensor on board and send their location to the main office. A big screen in the planning office shows the location of all the containers as well as the current traffic. The planers distribute the orders to external transport companies and react on exceptions during the transport process, such as traffic jams or accidents. The industry partner accepts new orders until six hours before the departure. This opportunity for the costumers leads to the requirement of a fast and flexible planning process.

Starting with an initial routing solution as described above and performing an ex post optimization, the central question arises as follows: How big are the improvements for objectives as total driven kilometers, costs, empty driven kilometers and time? This requires a specific planning approach in contrast to planning models that initially consider swap body transshipments.

3.2 Ex Post Routing Software

With respect to the situation described in Section 3.1 we have to develop an ex post routing software that assumes and improves an initial routing solution. According to the process of software development, we start with a requirements specification [18].

The data need to be exported from the current planning system for importing them in the optimization program as a CSV file. In the program the data is mapped to an object orientated data model. By taking care of all the restrictions and objectives the program starts to search for changing points. The result can be exported for the next steps. Below, we present a list of all required features by the industry partner for a software prototype. The features are divided in different feature sets:
- Import of the data from a CSV file: possible change points, orders, planned routes, distances of the transport net
- Aggregation of the routes to tours, mapping of the orders to routes, calculation of the key performance indicators (KPIs)
- Integration of all the restrictions and calculation goals
- Implementation of an algorithm with time windows and cost calculation
- Assumption of more than one possible containers per truck
- Export of calculation results, program log file, saving of calculation settings
- Implementation of customs check for the industry partner
- Graphical and console view
- Independency of operating system

4 Heuristic Routing Software

The developed heuristic routing software has two major components: A heuristic algorithm and a decision support system.

4.1 Heuristic Algorithm

The VRPTT represents a class of complex planning problems for which only few exact solution methods exist [5]. Furthermore, we have to consider additional restrictions in the practical case. Thus, we decided to use a heuristic routing algorithm for the prototype software and an evaluation of the potential of transshipment with swap bodies. Figure 3 presents the pseudo code for this algorithm.

The heuristic basically compares all the change possibilities and takes all the practical restrictions into account. A tour includes one or more routes. Every route gives a possibility to change containers. If the change point meets the settings of costs, distance and time savings, the change is classified as a possible change point. For the evaluation of the quality of the change points, special KPIs are defined. Due to the requirements of the industry partner a special point in the calculation is set up where specific coding can be included and more practical restrictions can be taken into consideration. The output of the heuristic is a flat list of change possibilities. The list is build up out of the export objects. The user can see in the log details, at what time the algorithm is working on comparing which solution.
FORALL routes DO
  FOR ALL routes DO
    IF route is on the same tour as the original one THEN
      STOP
    END IF
    IF two empty tours should be combined THEN
      STOP
    END IF
  FOR ALL change points DO
    IF both routes start or end at a change point THEN
      STOP
    END IF
    IF the combination has already been checked THEN
      STOP
    END IF
    IF no trailers for change are available THEN
      STOP
    END IF
    Assure that all the routes are driving to the change point
    Calculation of the new distances and route times
    IF time and costs need to be taken in consideration THEN
      IF time windows does not fit THEN
        STOP
      END IF
    END IF
    Creation of a new route with all the attributes
    Modification of the complete tour with the new route
    Calculation of the tour KPIs
    IF the costs are taken into consideration THEN
      Calculation the opportunity costs
      Calculation of the new costs
    END IF
    IF Check of the settings fails THEN
      STOP
    END IF
    Custom check part
    IF change partner found THEN
      Creation of the logs
      Creation of the export objects
    END IF
  END FOR
END FOR
END FOR

Figure 3: Pseudo code of the developed heuristic routing algorithm
4.2 Prototype Software

Figure 4 illustrates the functionality of the developed prototype software. The first step is to import the planning data. The screenshots show the successful import of the planning data into the optimization program.

Figure 4: Screenshots of the imported tour data and map

The data of the routes, change points, tours and orders can be controlled in the screen. A modification of the data can only be done by editing the original data and starting the import process again. The imported data can be displayed on a map. The screenshot demonstrates how this looks for a typical planning day.

The filter in the upper section of the program allows selecting only tours or changing points. The user can interact in the map by zooming and by switching the view. After a calculation for change points the new calculated routes are displayed on the map.

4.3 Decision Support for Operational, Tactical and Strategic Planning

Generally, decision support and planning models can be distinguished according to their planning horizon. In this section we demonstrate, how the developed approach can be integrated into operational, tactical and strategic planning.

4.3.1 Operational Planning

In operational planning a quick response time to changes on the plan are in the focus of the planners. Therefore, a quick calculation of possible combination via a change point has the highest priority in this step. The orders need to be checked for possibilities of combination. For this, all planned routes need to be checked. The calculation time for this is estimated as less than ten seconds. The advantage is that with a little effort routes can be checked for possible combinations. Once a combination is
found, the savings potential is displayed, too. Disadvantages can appear with long calculation times for the proposal of combinations. If the calculation takes too long, the calculation can be made in the background of the program, as soon as enough information is available for the calculation.

4.3.2 Tactical Planning

The primary objective of tactical planning is the improvement of the master plan, which is the basis for the operational planning. Every change in tactical planning has an influence on the operational planning. The process of the typical use of the prototype in tactical planning is shown in the section on the use of the software. The challenge in the use of the program in this context is to find data with a good quality for the calculation. In this example the planning data of a typical day is sufficient. For further analysis daily ups and downs need to be considered as well. As an extension of the program we propose to add a feature to compare the feasible solutions with each other. A prioritization of the objectives of the program can lead to an automatic choice of the best feasible solution.

4.3.3 Strategic Planning

The core objective of strategic planning is to make long-term decisions for the strategic direction of the company. Improvements on the plan are based on aggregated data from the operational and tactical levels. The goal of the use of this prototype can be to identify new change points in the transportation network. The higher number of change points has direct impact on the tactical planning, because now more change points need to be considered in the route planning. The costs for the use of a change point can be different. This leads to a detailed cost consideration of the change points. The fixed and variable costs of the change points can be set up in the import data. For an optimal use of the prototype for this scenario the software needs to have the possibility to compare the old with the new results of the calculation.

5 Computational Study

We tested the developed algorithm and routing software with real world data from the cooperating carrier. In this section we present general improvements of the ex post planning approach and perform a sensitivity analysis assuming different priorities for different routing objectives.

5.1 Ex Post Planning Results

We have tested the algorithm with planning data of 2792 orders which are planned on 1438 routes. Every truck drives with 1.94 swap body containers on average. Thus, many trucks have trailers. The routes are planned on 734 tours, meaning that every tour has 1.96 routes. In total 349418 kilometers are driven in 309329 minutes (5155.48 hours). For the first test all five hubs of the industry partner are used as potential change points. To fulfill the need of a good solution for the industry partner, these restrictions are set up:

- Minimal tour length: 1 kilometer
- Maximal tour length: 650 kilometer
- Minimal change time: 30 minutes
- Trailers can be used on every route

Table 1 gives an overview of the different savings:
Table 1: Comparison of the best calculation results

The comparison shows the improvement of vehicle routing by the developed algorithm. The increase of the number of change points leads to an increase of the savings. Facing these results we need to look into the computational times of the algorithm to show, where in the planning process the prototype can be used best. For this comparison we tested the computational times on a computer with the following specifications: Processor: Intel Core 2.60 GhZ; RAM: 8 GB; Operating system: 64-bit Windows 7 Enterprise System priority. These results make a use in all different stages of the planning process possible. For negative values in the table, the algorithm did not find any improvements but concluded deterioration.

5.2 Priority Sensitivity Analysis

In road transport and vehicle routing different objectives need to be considered. The developed planning software enables us to assign priorities to these objectives which are especially relevant in practice. Table 2 shows a sensitivity analysis under consideration of different priorities. We create each priority by assigning a dominant weight to one objective and an equally dominated weight to the other objectives.

Table 2: Sensitivity analysis assuming different strategies (different priorities for objectives)

The results are identical for the first three priorities. This happens because no savings of opportunity costs could be created and due to the assumption that driven kilometers cost 1 € and the use of transshipment point was not punished. For priority of empty tours, the strategy becomes clearly visible. Empty tours can be reduced more significantly, but this leads to more total driven kilometers, more costs and more time consumption.
6 Conclusion

Combined road transport with swap bodies creates opportunities for carriers to reduce costs, total driven kilometers, operating times and emissions. However, prior research has shown that this problem class is rarely focused in science and leads to challenging optimization models. Thus, there remains a need for appropriate planning models and routing software. In this paper we have developed a heuristic routing software regarding the case of a cooperating carrier and evaluated our approach with real world data under consideration of different planning priorities.

We found that the regarded case could be classified according to recent work by Drexl [5][6] and Mankowska et al. [12], but we had to model specific constraints to fulfill all requirements of the industry partner. We developed a heuristic algorithm and decision support software that take all these requirements into account. Furthermore, we demonstrated how this approach can be applied in operational, tactical and strategic planning of logistic organizations. We tested the software with real world data and observed significant reductions in costs, total driven kilometers and operating times. We were also able to assign priorities to different objectives and analyzed their interdependencies. Most notably, we demonstrated the potential of combined road transport and provided a solution method in the complex and emerging research field of vehicle routing with synchronization constraints.

While this paper used an ex post planning approach a comparison to an ex ante model would an interesting extension. Also, we plan to substitute the heuristic by an exact or a matheuristic method depending on time limits deemed practical. A further interesting extension could be the integration of emissions as a planning objective.

7 References


