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Development Of A Data Concept For An Algorithm To Enable Relay Traffic For Trucks

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Abstract

In road haulage, transports are interrupted by truck drivers to comply with driving and rest times. On long-distance routes, these interruptions lead to a considerable increase in transport time. Transport interruption can be avoided by so-called relay traffic: a vehicle (e. g. semi-trailer) is handed over to a rested driver at the end of the driving time. This type of transport requires a certain company size. In Germany, however, transport companies have 11 employees on average. Intra-company relay traffic is therefore not economically viable for most transport companies. To organize an intermodal transport across forwarding companies, long-distance routes need to be split into partial routes to divide them between freight forwarders and carriers. This paper presents a data concept for an algorithm to find the best possible route sections along a previously defined start and endpoint. The developed data concept includes order-specific data, forwarder-specific data, real-time traffic data, geographical data as well as data from freight forwarding software and telematics to be the basis for the route sectioning algorithm. In this paper, different data sources, external services and logistic systems are analyzed and evaluated. It is shown which data is needed and what the best ways are to select and derive this data from the different data sources.

Keywords

Relay Traffic; Route Sectioning Algorithm; Freight Forwarder; Carrier; Transport Order

1. Introduction

On long-distance routes, the driving and rest times truck drivers must comply with cause a considerable increase in transportation time [1]. The interruptions due to break times can be reduced by double staffing. However, double crews with two truck drivers are problematic and cost-intensive due to driver shortages as freight volumes increase [2]. Additionally, interruptions are not entirely avoided either since time as a co-driver does not count as rest time. In order to comply with driving and rest times, truck parking spaces are also occupied of which there is a shortage of around 23,300 on German highways according to BASt [3]. Furthermore, the parking-seeking traffic leads to CO_2 emissions, driving time overruns and frustration among truck drivers. Illegally parked trucks cause accidents, bother residents and encourage cargo robberies with damage running into billions [4]. Building more parking availabilities costs billions of dollars and, at the current rate of new construction, will not solve the problem for the next 20 years [5].

Transport interruption can be avoided by so-called relay traffic: a vehicle (e. g. semi-trailer) is handed over to a rested driver at the end of the driving time. While the driver who handed over the trailer can rest when his driving time is reached, the trailer continues his path with another driver. Therefore, relay traffic could

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help the parking problem because only the truck without the trailer needs to be parked. Nevertheless, this type of transport requires a certain company size since a network of drivers in different regions is needed. In Germany, however, 73% of the forwarding companies have less than 100 employees. On average, a transport company has 11 employees [6]. Intra-company relay traffic is therefore not economically viable for most transport companies. There is a need for an intelligent algorithm which is capable of planning this more complex method of transportation. So far, there is no solution for the organization of relay transport across forwarding companies. An explanation of this relay traffic transport system can be seen in Figure 1. For example, one delivery goes from Antwerp to Istanbul and the other way around. Instead of one driver driving all the way, the route is split into five sections. In this case the driver who starts in Antwerp only drives to a switching point near Frankfurt and drives back home with the trailer destinated for Antwerp. This principle repeats itself in the other five sections for the other drivers.

Figure 1: relay traffic transport system

2. Motivation

For the relay traffic transport system to function, a complex algorithm must be developed. The goal of the algorithm is to cleverly divide the complete route into smaller sections. Each section should be small enough to comply with the truckdriver's driving time. When the truckdriver finishes the section and arrives at the switching point for the trailer, the next truckdriver is already prepared and starts with the next section. For the algorithm to produce this output, it needs to take diverse types of data into account. Examples of this would be transport orders to consider the right start and endpoint, truck routing data to determine the estimated time of arrival and real-time traffic information to potentially adjust the estimated time of arrival. To clarify the data, which is needed for the algorithm to function properly, the goal of this research is to develop a data model for the algorithm. To create a basis for this data model, the status quo of truck transportation in Europe will be analyzed. By reviewing data about transportation management systems (TMS), routing software and possible switching points, it is examined which useful data already exists. Additionally, in the chapter "State of Research", it is clarified which vehicle routing problems and route sectioning algorithms already exist for other purposes, and if these can be adapted or function as a basis for the still to be developed algorithm. Moreover, the real time traffic data, which is an essential part of the algorithm, will be investigated to review the different traffic data gathering methods.

2.1 Truck transportation in Europe

2.1.1 Transportation management system (TMS)

TMS is a software that integrates supply chain management and plays a central role in logistic transportation. The TMS software allows freight forwarder and carriers to observe and control logistical operations. Hereby, the software integrates the different stages that make up freight transportation processes and contributes to the execution and control of the activities [7]. A TMS forms the logistical platform that enables freight forwarders and carriers to plan resulting transport requirements from procurement, distribution and returns management on available transport capacities. Scheduled tours can then be optimized and monitored until delivery [9]. These TMS functionalities can be divided into three groups [8].

- Planning and execution: determine the ideal transport mode, optimized route, and cargo consolidation for better use of vehicle capacity.
- Monitoring and control: provide real-time status information of vehicles and cargo transported by GPS tracking.
- Auditing and support to commercial negotiations stores a history of approved freight rates that seek to simplify the process of freight auditing.

Generally, all freight forwarder and carrier data e. g. transport mode, consolidation of different types of cargo, free driving time of truck drivers or order information is stored in a TMS. Which freight forwarder and carrier data will be needed for the data model of the algorithm will be further elaborated at 4.2.1

2.1.2 Routing software

Most vehicle routing issues are related to practical transportation issues. Each vehicle routing problem frequently has a unique solution that satisfies a particular set of constraints and goals considering the inherent variations in real-world environments that exist. Vehicle routing issues have typically been attempted using a variety of methods, from precise algorithms to heuristics [8].

For plotting the route for truck drivers, the routing software must consider truck specific parameters like permissible clearance height, maximum weight, speed limits and environmental zones [9]. To calculate the costs, truck, gasoline costs or the hourly rate of the driver are an essential part of the transport costs and must be considered and optimized by the routing software [9]. To compare the different routing software providers, various important aspects of truck routing software have been compared, as seen in Table 1.

Table 1: Comparison routing software

Table	PTV-Group	Google	Impargo	TomTom (Europe)	here
Price (Per Month/ per user)	49	Subscription	19,90	Subscription	Subscription
API Connection	✓	✓	✓	✓	✓
Route planning	✓	✓	✓	✓	✓
Traffic forecast	✓	✓	✗	✓	✗
Route cost calculation	✓	✗	✓	✗	✓
Truck navigation	✓	✗	✓	✓	✓
Realtime ETA sharing	✓	✓	✓	✗	✓
Offer calculator	✓	✗	✓	✗	✗

2.1.1 Possible switching points

For the relay traffic transport system to function, the algorithm needs a list of switching points spread through Europe. The switching points must contain a combination of parking spaces for trucks along with trailer changing areas. For the transport system to work, there will be several characteristics these spots must fulfill. Next to parking spaces and trailer switching areas, the switching points need to be near to the highway to prevent a costly and environmentally unfriendly detour. Furthermore, the switching points need to be a secured area in case the drivers arrive at different times and the trailer is unsupervised. Suitable are highway service areas, industrial areas, and premises of logistical companies. Public highway parking spaces are not applicable, because of parking shortage, safety reasons and costly detours. In Germany, there are 35.000 trucking parking places missing [3][4]. Especially at night, the parking places are overcrowded and leave no space for a trailer change. Moreover, public parking spaces are located at one lane of the highway, one of the trucks would have to take a costly detour to change the highway direction.

2.2 State of the Research

2.2.1 Vehicle routing problem

The term "Vehicle routing problem" (VRP) refers to a class of combinatorial problems where customers are to be served by several vehicles. [10], among others, have developed some well-known models for vehicle routing issues. [8] identifies three categories of vehicle routing issues which are linked to routing problems of truck transportation: “Truck and trailer routing problem” (TTRP), “Vehicle scheduling problem” (VSP) and “Vehicle routing problem with time windows” (VRPTW) [8].

[11] presents the TTRP (a variation of VRP) problem, which takes into account the fleet size of trucks and trailers in the model [11]. In the solution, there are three distinct types of routes: (1) routes where a truck travels alone; (2) routes where a truck and trailer are required; and (3) routes where a trailer is only needed at specific sub-tours. The goal is to reduce both the fleet's overall cost and distance traveled [8]. In contrast to the VRP, the needed route sectioning algorithm mandates that trucks visit switching stations to pick up the trailer. The route sectioning algorithm, which determines the switching stations for picking up or parking the trailer, could possibly be used for the route sectioning algorithm. Especially as the TTRP allows the outsourcing of tasks [11]. For example, the trailer could be dropped off at a switching point for another truck (of another hauling company) to be picked up again.

The vehicle scheduling problem (VSP) made the assumption that multiple trips could be taken to complete the routing to various sites [12]. Each journey consists of a pair of predetermined sources and destinations, each one identified by the beginning and ending times. The goal is to reduce the number of vehicles, the cost associated with deadheading trips (gas, driver, etc.), and the amount of time each vehicle is idle. The restrictions for this model include the travel distance and time required for routine maintenance and refueling, as well as the limitation that some tasks can only be performed by a particular type of vehicle. Contrary to the vehicle routing issue, the trips data is the only factor that determines whether a customer is visited more than once or not at all [8]. Although trips in the VSP are comparable to the idea of an order in a relay traffic system, the complexity of trailer type constraints is not present in the VSP. For the relay traffic algorithm to be designed, the trailer type constraint is an important aspect, because it must be ensured, that the transported trailer can be picked up by the planned vehicles.

Another variation of the well-known vehicle routing problem is the vehicle routing problem with time windows (VRPTW). In this problem, a set of constrained vehicles must be routed from a central depot to a group of geographically dispersed customers with predetermined time windows and known demands. The time window can be described as a single-sided or double-sided window. The pickup points typically state the dates by which they must be served in single-sided time windows traveled [8]. However, in a double-sided time window, the nodes impose both the earliest and latest service times. There will be a waiting period if a vehicle arrives before the node's earliest service time. Since a vehicle can only service fewer nodes if the waiting time is longer, this penalizes the transport management through either an increase in the number of vehicles or direct waiting costs. [13] lists a few of VRPTW's more recent publications. [14]'s surveys on the VRPTW that are available. The VRPTW offers the opportunity to include time windows into the algorithm. This could be used for the time windows at the switching points.

2.2.2 Route sectioning algorithms

A route sectioning algorithm first plots a route from a start to an endpoint and then divides the route into several sections, depending on the requirements defined in the algorithm. [9] developed a software which determines which truck should undertake which demand and how this truck should select the roads and make a schedule for the drivers. Their objective was to find the best route with scheduling including the optimal parking and refueling locations into the route [9]. Furthermore, [15] have also developed a heuristic route sectioning algorithm, which is designed to optimize the routing of heterogeneous electric vehicles. The algorithm optimizes the delivery routes and calculates where to recharge the battery [15]. The algorithm has two similarities with the algorithm proposed in this paper. Firstly, the charging points can be compared with the switching points. Both are previously determined points which can be used when needed. Secondly the remaining energy level of the battery can be compared with the free driving time left of the truck driver. Both must be considered when planning the optimal charging or switching point. Additionally, the algorithm developed by [16] shows the same similarities in their algorithm. They have developed an efficient heuristic algorithm for the alternative-fuel station location problem [16]. In Table 2 the three proposed algorithms have been compared with important aspects of the algorithm to be created. None of the mentioned algorithms focuses on relay traffic and the corresponding trailer exchange. Until now, no algorithm is equipped with the function of finding the optimal switching points for the trailers to be exchanged. Nevertheless, the approaches have shown aspects which could be used for the development of the algorithm.

Table 2: Comparison route sectioning algorithms

Table	Truck routing [9]	Electric vehicle [15]	Alternative-fuel [16]
Rout sectioning	✓	✓	✓
Designed for Europe	✓	✗	✓
Designed for Trucks	✓	✓	✗
Realtime Traffic	✓	✗	✗
Relay Traffic	✗	✗	✗

2.2.3 Real-time traffic data

Different data collection techniques can be used to collect and pre-process traffic data with different technical aspects and operational characteristics. Studies show that traffic data collection through crowdsourcing provides reliable travel time estimates with reasonable accuracy [17]. Google Maps is the only provider of this type of crowdsourcing. Mobile phone users all around the world utilize GPS data through the Google Maps application. Furthermore, Google Maps has access to local municipality data trough contacts such as road-specific information, road types, road works and speed limits. The combination of this information results in accurate traffic data. In a test the traffic data provided by Google Maps are compared with a traffic dataset collected through sensors installed on different road segments in the city of Paris. Google Maps traffic data achieved an overall accuracy of 95.8% in fluid traffic situations [18]. These test results show that the right use of crowdsourcing together with local municipality data can produce accurate traffic data which is needed for the algorithm.

3. Methodology

In this paper, a data model for an algorithm to enable relay traffic for trucks is developed by applying the systematic mapping study [19]. A systematic mapping study is conducted to get a comprehensive overview on a particular research topic and identify research gaps. The result of a systematic mapping study is a visual summary with various classification categories [20]. The procedure in [19] was followed, including the five phases of (1) planning of the study, (2) search execution, (3) selection of primary studies, (4) data extraction and classification, (5) analysis and mapping (see Figure 2). In the following, the five phases are descripted.

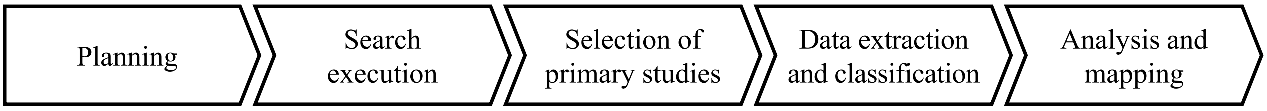

Figure 2: Approach for systematic mapping study

1. Planning: The planning phase exists of five steps:
    a. Definition of research question: How can a data model for an algorithm to enable relay traffic for trucks be descripted and where can the data be derived?
    b. Definition of the scope: Developing a data model for a platform approach by analyzing the algorithm procedure and identifying suitable data sources
    c. Establishment of search strategy: Only qualified journals are considered. In case of services and data which can be purchased, the offer of service and data providers are included.
    d. Establishment of selection criteria: For the journals, only recent papers in renowned logistic journals are selected. The offers of service and data providers still need to be marketed and purchasable.
2. Search execution: In this step, the search is executed based on the previously defined search strategy
3. Selection of primary studies: The primary studies are afterwards selected based on the selection criteria
4. Data extraction and classification: The classification scheme consists of the different steps the algorithm is performing and the different data that is needed for each step. Moreover, the different data sources are defined in detail.
5. Analysis and mapping: A concept for a data model is build and analyzed based on the findings from the previous steps

4. Results

4.1 Routing sectioning algorithm for relay traffic

The route sectioning algorithm to enable relay traffic determines which switching points are possible and comply with the driver's driving time. First, a route from a start to an endpoint is plotted based on the freight forwarder's transport order and truck routing data. Subsequently, it is the algorithms task to define route sections with suitable switching points for the trailer to be exchanged. When the switching points are defined, the route sections are plotted again for navigation purposes. Real-time traffic data is used to define the estimated time of arrival and potentially adjust the earliest starting and latest arrival times. Figure 3 shows the data model of the route sectioning algorithm for relay traffic including the needed data and results for each step.

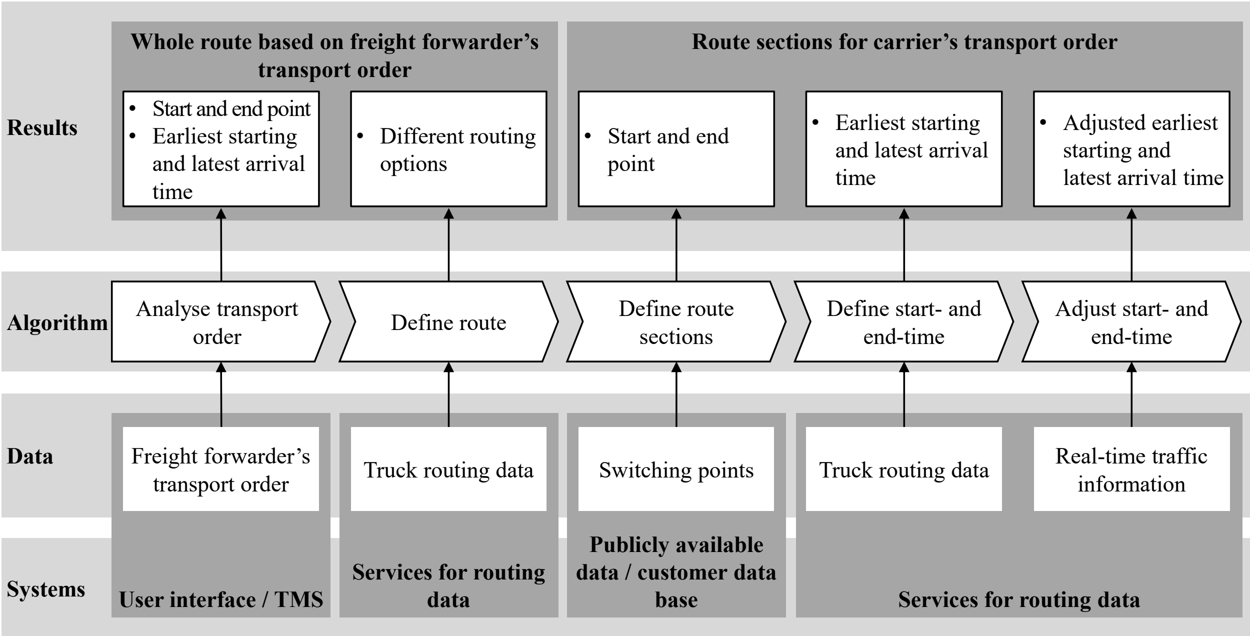

Figure 3: Route sectioning algorithm for relay traffic

4.2 Data model for sectioning algorithm

As a result of the systematic mapping study, the indispensable data input for the algorithm to function was identified. Transport orders, truck routing data, switching points and real-time traffic data have been researched to locate the most important aspects of these datasets for the algorithm.

4.2.1 Transport orders

Within this algorithm, there are two types of transport orders. The freight forwarder's transport order and the carrier's transport order. The freight forwarder's transport order contains the whole route defined by the shipper, who hired the freight forwarder to move a cargo from a given start to an endpoint in a given time. The freight forwarder's transport order can then be broken down to several carrier's transport orders, which consist out of route sections from the freight forwarder's transport order. From the freight forwarder transport order, the starting and arrival times as well as the start and endpoints must be integrated into the algorithm to then let the algorithm define the route sections with its switching points. The output of the algorithm is the carrier's transport order including the route sections and the corresponding starting and arrival times.

4.2.2 Truck routing data

Truck routing data is different from car routing data since additional information (e. g. tunnel heights and maximum load) is needed. Therefore, normal routing systems like Google Maps cannot be used. Research has shown that there are multiple providers of truck routing software's, as seen in Table 1 and **Error! Reference source not found.**. Furthermore, it shows how many of the chosen aspects are provided. The PTV-Group is the only provider who provides all the information needed. The truck routing data is particularly important for defining the route and scheduling transportation orders. With the truck routing data, the algorithm can define the expected starting and arrival times for the carrier's transport orders.

4.2.3 Switching points

The switching points are an essential part for the relay traffic algorithm to work properly. Without the right trailer changing areas the system cannot function efficiently. Therefore, a list of possible switching points for the algorithm to choose from must be created. In case there is no list with possible switching points from the freight forwarder or carrier database, three alternative options were identified. With great organizational efforts parking spaces at industrial areas or premises of logistical companies could function as switching points. The most promising solution however are highway service areas. Because here the relay traffic transport system and the highway service areas could form a symbiosis. The highway service could organize a trailer changing area in exchange for a switching fee. Furthermore, the parking problem could be dramatically reduced. Because when the trailer continuous its trip and only truck itself needs a parking space, up to three trucks would fit on a parking space previously used for a truck with trailer. This would reduce the truckdrivers searching time for a parking space and simultaneously benefit the highway service area. The service area could host up to three times more trucks and truck drivers.

4.2.4 Real-time traffic data

The use of real-time traffic data for planning optimal routes is indispensable [21]. The algorithm needs to have access to real-time traffic data for it to plan a route and to intelligently determine the switching points. Furthermore, this traffic data is important for reliable estimated time of arrival (ETA) predictions, so the forwarder and the other truckdriver know when the trailer will arrive or be delayed. The research has shown that that the right use of crowdsourcing together with local municipality data can produce very accurate traffic data with ich needed for the algorithm [21]. Although google maps provides no routing data for trucks, the traffic data could be very useful for the algorithm [21]. With usage of accurate traffic data, the algorithm will be able to adjust starting and arrival times based on changing traffic situations to determine accurate ETAs for the switching points. Because of the crowdsourcing capabilities of Google Maps, they deliver the most reliable real-time traffic data.

5. Conclusion and outlook

Within this paper, a data model for an algorithm to enable relay traffic for trucks was developed. In the first step, the existing data within transport management systems, routing software and switching points was described. Afterwards, the status quo of route sectioning algorithms and real-time traffic data was analyzed and approaches which could be used for the development of the algorithm were identified. With the application of a systematic mapping study, a concept for a data model was build. The data model is based on the different steps performed by the algorithm and shows data sources, the needed data and the results for each algorithm step. The main data typed needed for the algorithm are transport orders, truck routing data, switching points and real-time traffic data.

In the future, the algorithm could be enhanced by enlarging the requirements for finding the best switching points. The following adjustments were identified:

- An additional requirement would be to minimize the transport costs.
- Moreover, not only the maximum driving time of the truck driver could be considered, but the left amount of free driving time.
- Furthermore, the transported cargo could be an additional parameter for the algorithm. The information about dangerous goods and weight of the cargo could be added, since dangerous goods must be known, so possible road limitations can be prevented. The weight of the cargo is important for economic reasons, if small detours must be made to reach the switching point, the truck with the smallest weight should make the biggest detour.
- Additionally, should the traffic situation change, the algorithm could not only change the ETA and inform the second drivers, but be capable of changing the existing switching points so both drivers arrive at approximately the same time.

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Biography

Kira Frings (*1995) works as a project manager and scientific assistant at the Institute for Industrial Management (FIR) at the RWTH Aachen since 2021. Before that, she gained experience in requirements engineering and agile project management at the energy and software start-up envelio GmbH as a product owner and product manager.

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Florian Wehling (*1991) leads the technical development at MANSIO GmbH since 2022. Prior to that, he gained experience in software development at other startups. In 2017, he completed his computer science studies at RWTH Aachen University with a Master’s degree (M.Sc.).