Integration of Load Carriers in a Decentralized Routing Concept for Transport Logistics Networks

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Abstract: - In the field of transport logistics, the planning of routes is usually executed centrally. However, current trends in transport logistics exhibit higher degrees of dynamics and complexity. Central algorithms are not adequate in handling these new challenges. Therefore, new solutions are required. Within this context, the Distributed Logistics Routing Protocol (DLRP) for the autonomous and decentralized routing in transport logistic networks has been developed. In previous work, two types of logistic entities have been integrated within the DLRP, transport vehicles and transport goods. In order to evaluate the performance of the DLRP in scenarios, which are closer to reality, load carriers are integrated into the DLRP as a new type of logistic entities. Load carriers can be applied as supporting components for the transport of goods. Within this work, the concept of the integration of load carriers is presented. Furthermore, the influences of the integration are investigated. For that, different scenarios are generated, which enable the comparison with simulations without integrated load carriers.

Key-Words: - Autonomous control - Distributed logistics routing protocol (DLRP) – Transport logistics – Routing algorithm – Load carriers

1 Introduction

Nowadays, typical routing algorithms for transport logistics networks are algorithms to solve the Vehicle Routing Problem (VRP) [2] or the Pickup and Delivery Problem (PDP) [4]. But due to higher degrees of dynamics and complexity, central control is pushed to its limits when handling these new requirements. Therefore, new solutions are required [6]. Within the Collaborative Research Centre 637 (CRC 637) [7], the Distributed Logistics Routing Protocol (DLRP) for the decentralized routing in transport logistics networks has been developed. The DLRP is adapted from algorithms that are used in wireless ad-hoc communication networks.

In previous work on DLRP, routing has been performed for two types of logistic entities: transport vehicles and transport goods. However, different types of load carriers are additionally utilized in transport logistics networks (e.g. pallets or containers). These load carriers can often be regarded as supporting components. They can load the goods, whereas they have to be transported by vehicles. In previous work on DLRP, load carriers have not been regarded within the simulations. In order to evaluate the performance of the DLRP in scenarios that are closer to reality, load carriers need to be considered as a new class of logistic entities within the DLRP.

Within this work, the influences of the integration of load carriers are investigated. For that, scenarios have to be specified, which allow an adequate evaluation. The new type of logistic entities increases the complexity of the communication and leads to a further level of interaction between the logistic entities. Hence, the performance of the DLRP after the integration has to be evaluated. For that, a comparison with the results before the integration of load carriers is important.

2 The Distributed Logistics Routing Protocol

The Distributed Logistics Routing Protocol (DLRP) is a decentralized routing method. Its basic concepts are based on algorithms for wireless ad-hoc communication networks. Within these networks, routes have to be found in a dynamically changing topology. The routing algorithms for data communication packets have been adapted for the routing of logistic entities within transport logistics networks [5].

Basic topologies of scenarios for the DLRP consist of a graph with vertices, which represent logistic distribution centers, and edges between these vertices. The edges represent road connections. A sample topology is presented within Fig. 1, it has already been published in [1]. The figure illustrates a simplified map of Germany. The graph contains 18 cities of Germany and important motorways between the cities.

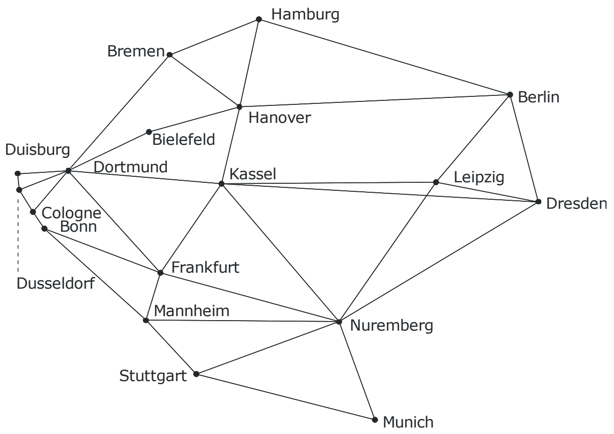

Fig. 1: Scenario topology

Two types of logistic entities, transport vehicles and transport goods, are simulated within the DLRP. The entities perform routing decisions autonomously. Therefore knowledge is shared between the logistic entities: The routing is done by using a route discovery messaging that is similar to source routing methods in ad-hoc communication networks. Whenever a logistic entity decides to plan a route, it sends communication messages through the network. These messages are called route requests. Route requests are transmitted to the neighbor vertices. Each vertex adds its local knowledge about the current network status and about announced routes of other logistic entities to the route request. Then the request is forwarded to the neighbor vertices, thereby loops are avoided. If the destination vertex of the routing logistic entity receives the route request, a route reply is transmitted directly back to the logistic entity. Thus, the logistic entity gains collected knowledge about a possible route through the network. The logistic entity can receive further route replies, each reply contains knowledge about one route. After receiving several route replies, the logistic entity renders its routing decision, based on the collected knowledge. Vertices, belonging to the chosen route, receive a route announcement. This information is essential for routing decisions of further logistic entities.

Routing decisions are dependent of collected knowledge: Routes, which are passed by a high number of transport vehicles, have a higher potential for transport goods than other routes. Correspondingly, transport vehicles prefer routes with a high flow of transport goods. Moreover, there are further decision criteria, like route length and so on. The most important decision criteria depend on the particular aims of the logistic entities. These are free to choose. They can be adapted to the particular scenario, which is an aspect of the flexibility of the DLRP. Another aspect is the possibility of replanning. If a “better” route (according to the decision criteria of the logistic entity) is discovered, the old route can be disannounced. More details towards the DLRP are described in [5].

The DLRP has been evaluated against heuristic methods that are traditionally applied to solve the Vehicle Routing Problem (VRP) and the Pickup and Delivery Problem (PDP). These algorithms are used for classical logistic routing scenarios. There are some important differences between the DLRP and these algorithms. For example, planning within the DLRP is executed dynamically, whereas the compared algorithms turn out a-priori plans. Due to the differences, the algorithms have been compared with some essential adjustments. The results show a good performance of the DLRP [3].

3 Integration of Load Carriers

In addition to the established logistic entities within the DLRP, load carriers are integrated as a new type of logistic entities. The aim is to evaluate the DLRP in scenarios that are closer to reality. The integration of the new type facilitates the simulation of further components that are used in transport logistics (e.g. palettes, containers, …).

3.1 Relations between the logistic entities

The integration of load carriers leads to an expanded hierarchy of the logistic entities. One possible, simple hierarchy is presented in Fig. 2. It is divided into three levels. The load carriers are applied to transport the goods, whereas they can be transported by vehicles. Additionally, the possibility that the goods are directly transported by the vehicles remains. In order to present the concept, only one class of load carriers is integrated into the DLRP within this work. Further classes of load carriers can expand the hierarchy by further levels.

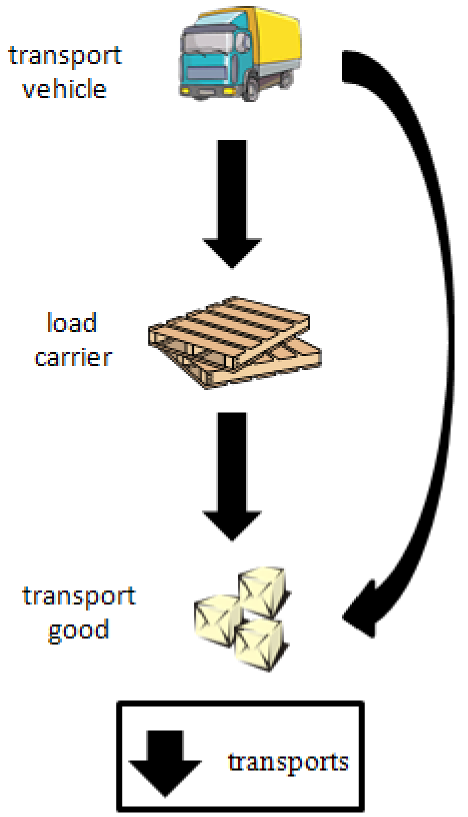

Fig. 2: Hierarchy of logistic entities

3.2 Routing process

Compared to transport vehicles and transport goods, load carriers exhibit different properties. Load carriers are transported by vehicles. Hence, the effort for transshipments of transport goods is high. For example, before it is possible to load/unload transport goods on/from a load carrier, the transporting vehicle should unload the load carrier first. To avoid the high effort, transshipments of transport goods on/from load carriers are restricted to the departure and destination vertices of the carriers. Hence, an adequate application area for this new type of logistic entities is the transport of goods with the same destination. Load carriers are especially beneficial for transport routes with a high flow of transport goods.

The planning of a new route for a load carrier is dependent of the transport goods that arrive or emerge at its actual vertex. Due to the high effort for transshipments an efficient employing of the load carriers should be ensured. Therefore a high utilization should be achieved. Within this work, a minimal utilization of 80% is aspired. If the number of transport goods at the actual vertex with the same destination is adequate to serve the minimal utilization, the transport goods can be loaded on the carrier. Then the destination of the load carrier is adjusted to the destination of the transport goods.

The routing process for the load carrier starts, when the capacity of the load carrier is achieved. Another trigger for the routing process is the due time of the transport goods. If the difference between the actual simulation time and the earliest due time falls below a threshold, the routing process is initiated. Hence, a missed departure time of transport goods is avoided. Communication with transport vehicles and routing decisions are performed by the first transport good on the load carrier. By transmitting route requests and route announcements (section 2), the information about the cargo of the load carrier is submitted to the transport vehicles. This ensures that the vehicles can adjust their plans, according to the number of transport goods on the load carrier. Here, transport processes, which lead to a high capacity, are more profitable for the vehicles.

4 Evaluation

To evaluate the concept, we compared the results after the integration of load carriers with the results before the integration.

4.1 Scenario description

The influences have been evaluated in scenarios with the topology presented in Fig. 1. Twelve transport vehicles are integrated into the scenario. Each vehicle can transport either 12 transport goods or one load carrier. 1000 transport goods are generated dynamically within the scenario. The most capable application area of load carriers is the transport on routes with a high flow of transport goods (section 3.2). Therefore, three routes have been predefined for each scenario. A variable contingent of the 1000 transport goods is generated on these routes. This means that the end vertices of the routes are the departure and the destination vertices for these transport goods. On each of these routes, four load carriers are available. The load carriers exhibit a capacity of twelve transport goods. The loading process starts, when an utilization of 80% can be achieved (see section 3.2).

10 scenarios with different predefined routes have been created. Departure and destination vertices of the transport goods, which are not allocated to the predefined routes, are uniformly distributed among the scenario topology. The

contingent of transport goods on the predefined routes is increased in 10%-intervals, from 0% to 100%. Hence, 11 intervals are investigated. Each scenario is combined with each interval, therefore we investigate 110 combinations. For each combination, two simulation runs are performed: one simulation run without load carriers, one simulation run with load carriers. To enable a comparison of the results, the simulation runs are terminated at the same time.

4.2 Evaluation results

In the following, the evaluation results are presented and discussed. Important logistic target values for the integration of load carriers are the portion of delivered transport goods and the number of transshipments. The achieved target values for the scenarios are presented in the following figures. The x-axis of all figures represents the contingent of transport goods that are allocated to the predefined routes for each simulation run. At a contingent of 0%, the departure and destination vertices of all transport goods are uniformly distributed among the scenario. If the value for the contingent is 100%, the departure and destination vertices of all transport goods are allocated to the predefined routes.

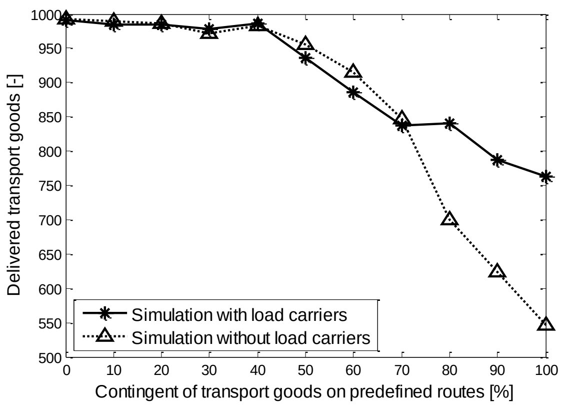

Fig. 3: Delivered transport goods

Fig. 3 presents the number of all transport goods successfully delivered within the simulation time. Beyond a contingent of 70%, the values for simulations with load carriers are higher than the values for simulations without load carriers. Until this contingent, the values are approximately equal. The reason is the allocation of the departure and destination vertices of the transport goods among the scenario topology. At uniform allocations, a better performance for the route planning for transport vehicles can be achieved. At a high contingent, the allocation is primarily restricted to the end vertices of the predefined routes. This leads to negative influences on the routing process without load carriers. The handling of non-uniform allocations is a limitation of the DLRP. By integrating load carriers, the effects of this limitation can be reduced. The new type of logistic entities causes a concentration of several transports goods (which have been loaded onto the load carrier) to single routes. This leads to the effect that the transport vehicles can plan their routes more effectively: due to the higher number of transport goods on one route, the possible revenue for the vehicles is increased. This has positive influences on the routing processes for the logistic entities.

A further logistic target value, the transshipments of transport goods, is presented within Fig. 4. The figure shows the values for transshipments of successfully delivered transport goods within the simulation time. In this regard, there is no difference between transshipments on transport vehicles or transshipments on load carriers. The sum of both numbers of transshipments is calculated. In order to get the average number of transshipments per transport good, the values have been normalized to the number of successfully delivered transport goods.

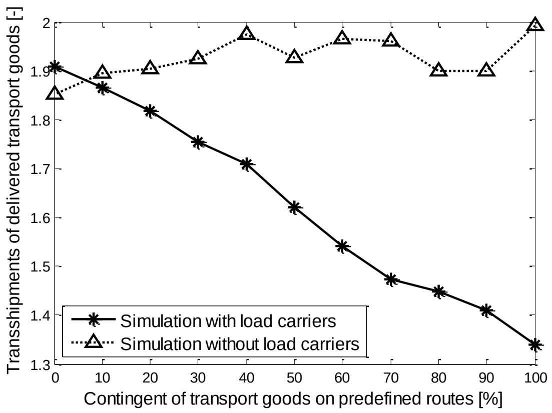

Fig. 4: Transshipments of delivered transport goods

It can be recognized that the values for simulations with load carriers are better than the values of simulations without load carriers. The exception is the value for a contingent of 0%. This performance could be expected, due to the fact that load carriers do not unload their cargo before the arrival at the destination vertex. This leads to a reduction of transshipments. At a high contingent, the minimal value of *~1.35* is achieved for simulations with load carriers. A lower value cannot be achieved, because transport goods have to be transported directly by vehicles sometimes. Possible reasons for the transport by vehicles are the temporal unavailability of load carriers or of further transport goods with the same destination.

The concept of integrating load carriers has different advantages. First of all, transshipments can lead to a high time effort. The transshipment values for simulations with load carriers are better; hence, time can be saved. Furthermore, transshipments can exhibit the risk of accidents. These can lead to negative effects on transport processes, e.g. to time delays. In addition, it is possible that transport goods are damaged. Consequently, a lower number of transshipments lead to advantages for the delivery of transport goods. However, the reduction of transshipments reduces the flexibility of the DLRP. It is possible that negative influences on the routing processes are the consequence. In future work, this aspect will be investigated, in comparison to the described advantages of the reduction of transshipments.

Additionally to the comparison between the results for simulations with and without load carriers, the simulations with load carriers are further investigated. The results for transport goods, allocated to predefined routes, are compared against the results for further goods. For that, the effects of the integration of load carriers on the two groups of transport goods are investigated. These results for simulations with load carriers are presented within Fig. 5 and Fig. 6.

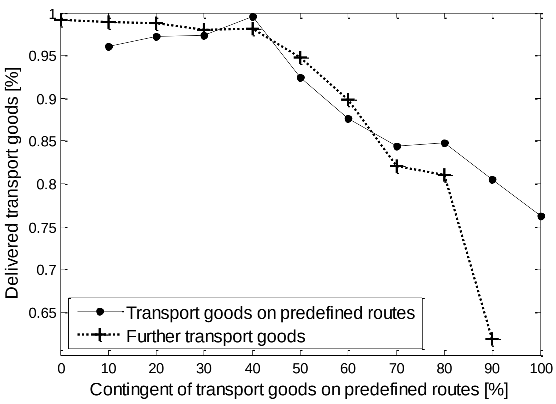

Fig. 5: Delivered transport goods for simulations with load carriers

Fig. 5 presents the values for successfully delivered transport goods within the simulation time. One line chart presents the portion of delivered goods allocated to the predefined routes, the second line chart presents the according values for further goods. Beyond a contingent of 70%, the values for transport goods allocated to the predefined routes are better. The results are comparable with the results presented within Fig. 3. Load carriers lead to advantages, when departure and destination vertices of transport goods are not uniformly allocated among the scenario topology. In case of uniform allocations, load carriers have moderate negative influences on the logistic performance of the DLRP.

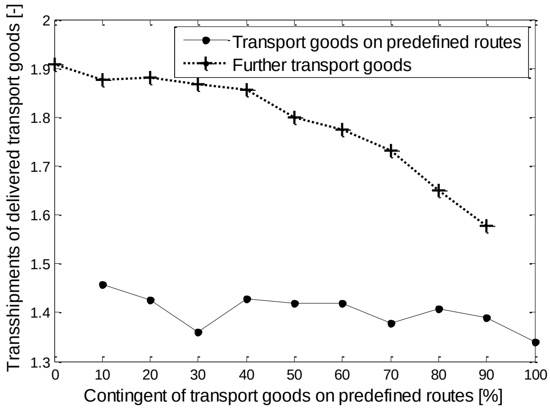

Fig. 6: Transshipments for simulations with load carriers

Fig. 6 presents the values for transshipments. The numbers of transshipments are normalized to the number of successfully delivered transport goods. The line charts present the values for transport goods, allocated to predefined routes, and for further goods. The results for transport goods for predefined routes are continuously better. Hence, the integration of load carriers leads to advantages for routes with a high flow of transport goods.

5 Conclusion

The results show that the DLRP can handle the integration of load carriers. This has various advantages. One important advantage is the reduction of transshipments. Transshipments can lead to negative influences on transport processes (e.g. delays); hence, it is benefiting to reduce the number of transshipments. Furthermore, the handling of load carriers within the DLRP exhibits advantages in special scenarios, in which the transport goods are allocated to predefined departure/destination vertices. For these scenarios, the application of load carriers leads to a higher portion of delivered transport goods.

In contrast to the positive effects, it is possible that the reduction of transshipments leads to negative effects on the transport processes and on the logistic performance, due to the lower flexibility for route planning. Here, it is necessary to investigate and compare the positive and the negative effects in future work.

Furthermore, an extension of the concept for load carriers seems to be reasonable. Here, it should be facilitated that the load carriers can leave their actual vertex without cargo. If not enough transport goods are available at the actual vertex, a load carrier cannot perform his function. In that case, it is reasonable to check, if there is a demand at the surrounding vertices for a load carrier. Hence, it should be facilitated that the load carrier can leave his actual vertex, in order to serve the demand.

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