Proceedings of the 21st International Conference on Modelling and Applied Simulation (MAS), 016
19th International Multidisciplinary Modeling & Simulation Multiconference

2724-0037 © 2022 The Authors.
doi: 10.46354/i3m.2022.mas.016

Order Assignment Strategies for Heterogeneous in-Bound Transport Systems

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Abstract

An efficient design of in-bound transport systems is crucial to meet the challenges of performance and reliability facing logistics, as they represent a central part of production and distribution systems. Moreover, these systems often consist of a heterogeneous fleet of vehicles, e.g., forklifts, tugger trains, and automated guided vehicles. Besides the vehicles' different technical and physical aspects, control strategies also significantly impact the system performance. Therefore, order assignment, i.e., how transport orders are distributed among the vehicles, is of primary importance. This work presents a new method based on the Hungarian algorithm for dynamically solving the transport-order assignment problem. For an exemplary transport system, we then use discrete event simulation to study the impact of different assignment strategies on the system performance.

Keywords: in-bound transport systems; Transport order assignment; discrete event simulation; optimization

1. Introduction

In-bound transport systems play a central part in logistics networks, as they ensure the material flow within production and storage areas (VDI-2689, 2019). Designing such systems is a complex task since it involves considering many factors influencing the system's performance. One key aspect is the selection of the order assignment strategy. A previous work (Mestiri et al., 2021) presents a generic simulation model to analyze heterogeneous transport systems' performance accurately. However, the model uses a vehicle-initiated strategy to distribute the transport orders to the vehicles. Since the strategy is decentralized, a global optimization could not be obtained.

To tackle this problem, we present a transport-order initiated order assignment strategy for heterogeneous transport systems in this work. Using discrete event simulation (DES), we then evaluate the influence of the different strategies (vehicle-initiated and transport-order-initiated) on the performance of an exemplary transport system.

The structure of this paper is as follows: In section 2, we present some related works. Then, in section 3, we describe the developed order assignment methods, which we evaluate in section 4. Finally, in section 5, we summarize the paper and give an outlook on future work.

2. Literature Review

The research by M. Mirlach and W. Günthner (2013) tackles the assignment problem of complex transportation systems with spatially distributed sources and sinks using a homogenous fleet of forklift trucks. Several assignment procedures were evaluated using DES by comparing the required fleet size to achieve the required throughput in a defined use case.

Lieb (2021) developed various static and dynamic control and order assignment strategies for homogeneous tugger train systems. Using DES, he conducted a quantitative analysis of these strategies' impact on the system's performance.

Rashidah et al. (2019) studied the factors that contribute to optimizing the performance of automated guided vehicles (AGV). They also present a genetic algorithm to assign transport orders, which they evaluate using a simulation model. Finally, Liu et al. (2020) developed an optimization method to solve the order assignment problem of AGV in order picking systems, which shows a performance increase compared to a non-optimized method.

Order assignment strategies are well studied in the scientific literature. For the different transport vehicles, various exact and heuristic methods are used to optimize the performance of transport systems. A heterogeneous fleet consisting of a combination of forklifts, tugger trains, and AGV is, however, to the best knowledge of the authors, not addressed.

3. Assignment Algorithms and Implementation

To evaluate and show the difference between the vehicle-initiated assignment method and a transport-

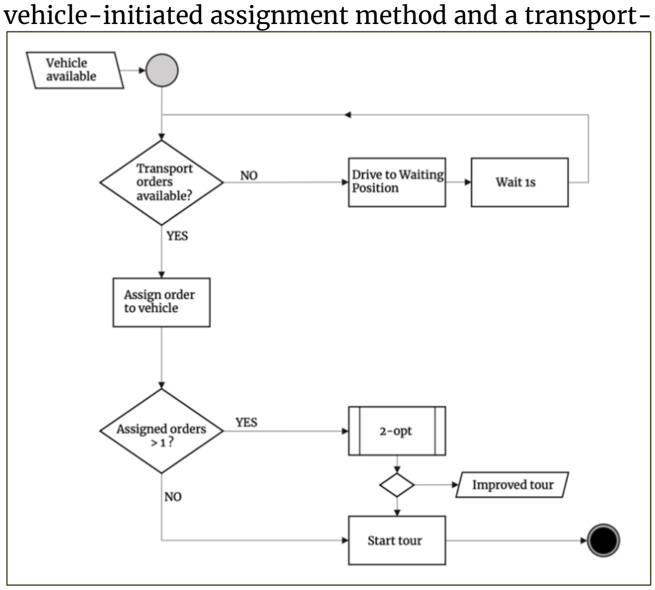

Figure 1. Process flow of the vehicle-initiated assignment method

order-initiated assignment method, the generic simulation model introduced in (Mestiri, Jamil, & Fottner, 2021) is expanded. This model is already equipped with a vehicle-initiated assignment method, which means every time a vehicle gets available, usually right after it has dropped off a load unit, it calls the assignment method. Figure 1 illustrates the schematic process.

If orders that can be processed by the specific vehicle are available at the time of the method call, they get assigned following the first in, first out strategy. Otherwise, the vehicle will drive to the given waiting position and call the method again in 1 second. If the vehicle's capacity is more significant than one and already has one or more orders assigned, the route is optimized using the 2-opt heuristic. After the successful assignment, the vehicle starts its tour.

Figure 2 shows the process flow of the implemented transport-order initiated assignment method. In this strategy, the vehicles do not call this method when available. Instead, after dropping off all Load units, the vehicles drive to their waiting positions to reduce congestion at the sinks. During this trip, the vehicles are considered available for new orders.

This assignment method is called every time a new order is generated. If no vehicle is available, the method restarts after 1 second. When there are available vehicles, a cost matrix is created containing all available vehicles in the rows and all currently open orders in the columns. The cells represent the related costs for the vehicles to process the orders. These costs can be the total distance driven from the current position to the source to the sink or the total process time.

Since the capacity of tugger trains is more significant than one, they appear multiple times in the table, once for

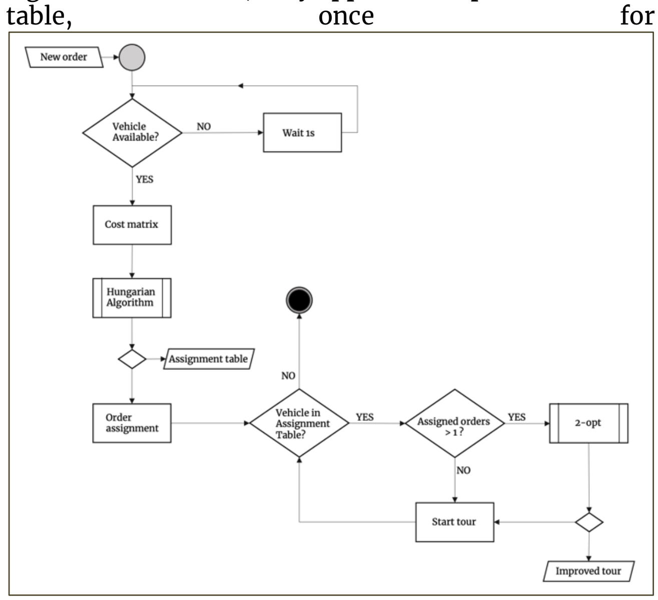

Figure 2. Process flow of the transport-order initiated assignment method

each available capacity.

To find the best assignment, the Hungarian Method minimizes the overall cost of this cost matrix (Kuhn, 1955). The resulting assignment table consists of the vehicle-transport order relations. Based on this table, the orders are assigned to the corresponding vehicles, and the specific routes are created. If two or more orders are assigned to the exact vehicle, the route will be optimized using the 2-opt heuristic.

4. Evaluation

4.1. Use case

Figure 3 illustrates the schematic layout of that model. It consists of several sources located on one side of the system and several sinks located on the opposite side. The sinks and sources are connected via one-way roads organized in a 10x10 Manhattan grid.

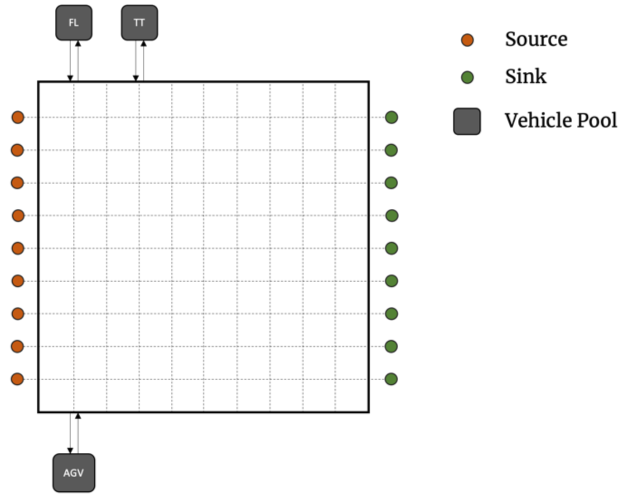

Figure 3. Schematic layout of the simulation model

This system uses as transport vehicles a combination of forklifts (FL), tugger trains (TT), and automated guided vehicles (AGV). Table 1 shows the different parameters of these vehicles. The loading capacities of the forklifts and AGVs correspond to those of one loading unit (LU) and those of the tugger trains of five loading units. Furthermore, there are waiting locations for all vehicle types (vehicle pools).

Table 1. Vehicle Parameters

Vehicle	Capacity	Speed loaded/ unloaded [m/s]	Acceleration loaded/ unloaded [m/s2]	Load handling time [s]
FL	1	5 / 5	1,05 / 0,89	6
AGV	1	1,5 / 1,5	0,5 / 0,5	10
TT	5	3,6 / 2,08	0,72 / 0,42	4

4.2. Simulation Results

The comparison of the assignment methods focuses on the average throughput per hour and the average cycle time. In addition, the rate of order generation is set to be above the system limit. This ensures that the maximum achievable performance is determined and compared for all variants of the assignment methods. Table 2 shows the parameters used in each simulation experiment.

For the TOI method variant, the process is triggered by creating a new order. Still, since no optimization exists, this order is randomly assigned to an available vehicle, not to favor a specific type of vehicle. Therefore, the comparable lower throughput that results from this assignment method is because the tugger trains are not using their full capacities due to the randomness in the assignment.

Table 2. Experiment Parameters

Nr.	Abbreviation	Method used	Routing optimization	Assignment optimization	# FL	# AGV	# TT	Simulation time
1	VI	Vehicle initiated	-	-	4	4	20	5 days
2	VI – 2-opt	Vehicle initiated	2-opt	-	4	4	20	5 days
3	TOI	Transport-order initiated	-	-	4	4	20	5 days
4	TOI – 2-opt	Transport-order initiated	2-opt	-	4	4	20	5 days
5	TOI – HM	Transport-order initiated	-	Hungarian Method	4	4	20	5 days
6	TOI – HM – 2-opt	Transport-order initiated	2-opt	Hungarian Method	4	4	20	5 days

As shown in Figure 4, the highest throughput is obtained using the transport-order initiated assignment method combined with the Hungarian Method and the 2-opt heuristic. It also shows the significant impact of the 2-opt heuristic. For both the vehicle-initiated strategy and the transport-order initiated strategy using the Hungarian Method, the model's throughput is increased by 41%. This effect is less significant with the transport-order initiated method without the Hungarian Method. This is due to the lower utilization of the tugger trains capacities, which results in fewer optimization possibilities

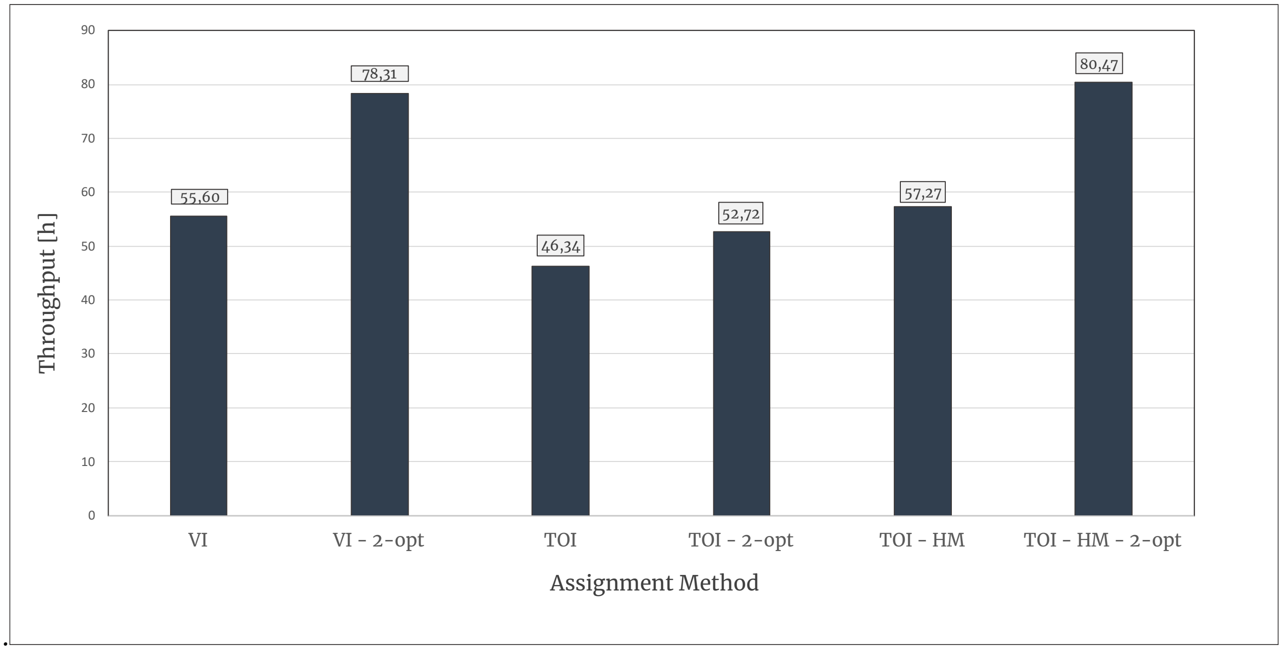

Figure 4. Simulation results for experiments 1 – 6: Throughput per hour averaged over all commodities

Figure 5 shows the average cycle times obtained with the different assignment strategies. The lowest cycle time is obtained using the transport-order initiated methods without the Hungarian algorithm. This is because tugger trains are usually not at their total capacity, and most tours are direct trips. Using the Hungarian algorithm with the 2-opt heuristic, a 31% decrease in the cycle time is achieved compared with the vehicle-initiated strategy VI.

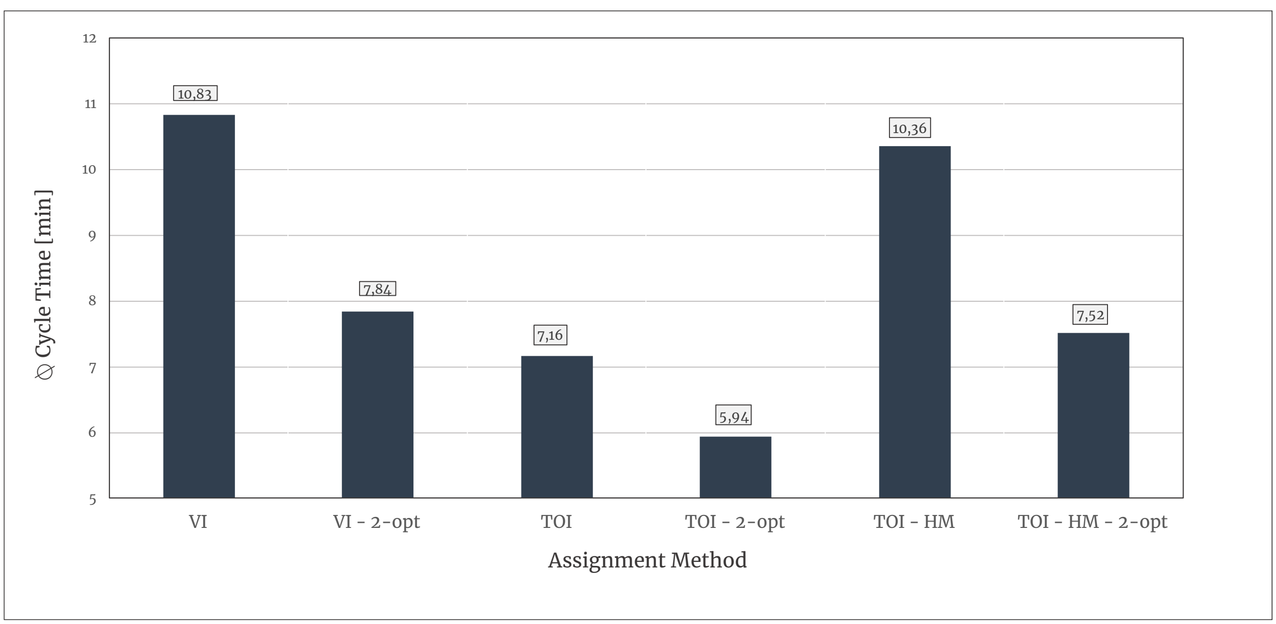

Figure 5. Simulation results for experiments 1 – 6: Cycle time averaged over all commodities

4.3. Discussion of the results

The influence of the different order assignment strategies on the performance of the transport system strongly depends on the considered use case. An example is the effect of the 2-opt heuristic as described in the previous section. When comparing the improvements obtained from the route optimization with those obtained from the assignment optimization, it is noticeable that the route optimization via the 2-opt heuristic significantly influences the system's performance more than the assignment optimization. This is explained in the first place by the strict local separation of sources and sinks within the layout. As a result, the vehicles must travel a comparably long distance to reach the next source. If, on the other hand, the sources and sinks were distributed differently, the selection of the vehicle would have a more significant influence since the current location of the vehicle would play a much more substantial role. Furthermore, the fleet composition used in this case contains more tugger trains than AGVs or forklifts. This results in more complex routes and, thereby, more improvement opportunities.

Since the tugger trains process up to five orders simultaneously, assigning an order to a tugger train changes the total distance to be driven and, therefore, the costs of all assigned orders. Therefore, to calculate the costs independently of the remaining orders, the distance/time needed for the tugger trains to drive to a particular source is set to be the distance/time to drive from the current position to the corresponding source divided by the tugger trains' capacity. This simplification can be made since the order is usually assigned to a vehicle at a sink right after the drop-off or at the waiting position. Therefore, the resulting distance to the sources' location has a more significant impact on the costs than the distance from one source to another.

Furthermore, the distance from the source to the sink of one specific order is defined as the direct way from the corresponding source to its sink without considering the possible drop-off points of the remaining orders. This simplification is justified by the large distances between sources and sinks compared to the distances from one source to another.

The transport order assignment using the Hungarian method and 2-opt (TOI-HM-2-opt) offers higher throughput values. However, it also presents a significantly higher computation time (approximately three times higher than the TOI – HM), as shown in figure 6, which results in a much longer run time for the simulation model. This is explained by the fact that the 2-opt algorithm must be run at each iteration of the Hungarian algorithm. Furthermore, compared to the transport-initiated strategy without optimization, the vehicle-initiated strategy consumes considerable time due to the sorting algorithm that identifies which open orders can be executed with the concerned vehicle.

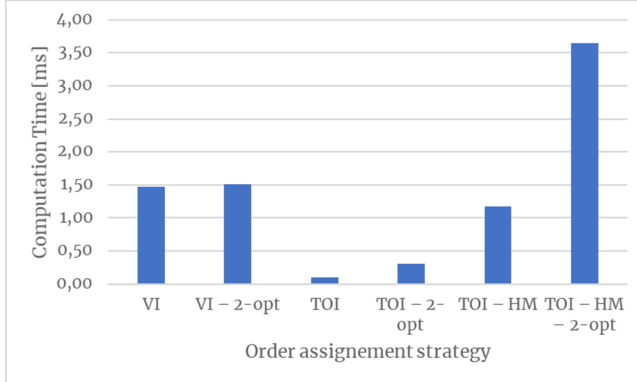

Figure 6. The average computation time of the different order assignment procedures

5. Conclusion and future work

In this work, we present a transport-order initiated algorithm, which uses the Hungarian Method to optimize the transport order assignment globally in the transport system. Using a discrete event simulation model, we then evaluate the effect of this strategy on the overall system performance by comparing it with the existing vehicle-initiated strategy. We show an increase in the system performance for the described throughput.

In future work, we will implement a new routing algorithm to reduce congestion in the system. This can be achieved statically, using linear optimization methods, and dynamically, using appropriate algorithms. Furthermore, to reduce traffic jams at sources and sinks, a simulation-based approach will be developed to accurately design the buffers connecting the transport system to the sources and sinks.

Funding

This work was part of the research project IGF Nr. 20959 N/1 / AiF Nr. 20959 N/1 of the research coalition "Intralogistik / Fördertechnik und Logistiksysteme (IFL) e.V" (iFL) and was promoted by the program for industrial alliance research (IGF). The financial support by the "German Federal Ministry for Economic Affairs and Climate Action" via the consortium "AiF" is gratefully acknowledged.

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