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Modified Adaptive Large Neighborhood Search for Scheduling Automated Guided Vehicle fleets considering dynamic transport carrier transfers

Angepasste Adaptive Large Neighborhood Search zur Einsatzplanung von Fahrerlosen Transportsystemen unter der Berücksichtigung dynamischer Ladungsträgertransfers

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The performance of Automated Guided Vehicle systems is highly related to the implemented control strategies for vehicle fleet management. Especially the assignment of transport carriers to vehicles and the decision on the processing sequence have a high impact.

So far, a dynamic transfer of transport carriers between the vehicles of an Automated Guided Vehicle fleet has not been sufficiently investigated. Nevertheless, applications from other areas like passenger transport or courier services show promising results in reduced vehicle movements and delivery times.

However, the approaches to generate solutions of these problems cannot be applied to the control of Automated Guided Vehicle systems. These planning tasks differ significantly in modeling (e.g. the use of a single depot as start and end for all vehicles) and solution generation (e.g. no real-time requirements). Hence, there is no sufficient control approach for Automated Guided Vehicle systems considering dynamic carrier transfers.

A heuristic approach adapted to the control of Automated Guided Vehicle fleets in intralogistics systems is presented in this article. The approach is called Modified Adaptive Large Neighborhood Search. The article describes the basic concepts of the approach and the adaptions to the field of application. Experiments based on generic test instances prove that the approach is sufficient to plan transfer operations for small vehicle fleets. Furthermore, potentials and limitations for the application in industrial systems are discussed.

[Keywords: Automated Guided Vehicle, Transfers, Scheduling, Heuristic, Adaptive Large Neighborhood Search]

Die Leistungsfähigkeit eines Fahrerlosen Transportsystems ist stark von der Steuerung der Fahrzeugflotte abhängig. Besonders die Zuordnung von Ladungsträgern und Fahrzeugen sowie die Festlegung der Abarbeitungsreihenfolge haben einen großen Einfluss.

Ein möglicher, gegenseitiger Austausch von Ladungsträgern zwischen den Fahrzeugen eines Fahrerlosen Transportsystems wurde bisher nicht umfassend untersucht. Gleichzeitig zeigen Anwendungen aus anderen Einsatzgebieten fahrzeugbasierter Systeme wie bspw. der Personentransport oder der Transport durch Kurierdienste vielversprechende Ergebnisse, wie eine Reduzierung von Fahrzeugbewegungen und Lieferzeiten.

Diese Ansätze zur Planung von Transporten lassen sich nicht direkt auf den Anwendungsfall Fahrerloses Transportsystem übertragen, da sich die zugrundeliegenden Annahmen hinsichtlich der Modellierung (z. B. ein einzelnes Depot als Start- und Zielpunkt aller Fahrzeuge) und der Lösungsgenerierung (z. B. keine Echtzeitanforderung) stark unterscheiden.

Ein heuristischer Ansatz, adaptiert auf die Steuerung von Fahrerlosen Transportsystemen in der Intralogistik, wird in diesem Beitrag vorgestellt. Der Ansatz wird als Modified Adaptive Large Neighborhood Search bezeichnet. Der Artikel beschreibt das Konzept des Ansatzes und die erforderlichen Anpassungen für das Einsatzfeld. Experimente anhand generischer Testinstanzen zeigen, dass der Ansatz geeignet ist, um Transfers zwischen den Fahrzeugen kleiner Flotten zu identifizieren. Darüber hinaus werden Potenziale und Hindernisse für den Einsatz in industriellen Anwendungen herausgearbeitet.

[Stichworte: Fahrerloses Transportsystem, Transfers, Scheduling, Heuristik, Adaptive Large Neighborhood Search]

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1 MOTIVATION

Automated Guided Vehicle (AGV) systems are essential for automating transport tasks in logistics and manufacturing environments. They allow a high degree of flexibility, which is crucial for the realization of modern logistics systems. To further increase the flexibility and the efficiency of AGV systems, new approaches to control are required.

The scheduling of AGV fleets offers the potential to integrate additional functionalities that can increase system flexibility. One option is to enable vehicles to exchange transport carriers during the transport process dynamically, depending on the current system state and not statically predefined.

Scheduling describes the assignment of transport orders to vehicles and the determination of the processing sequence. There are two categories of approaches for scheduling AGV systems. Most common are scheduling techniques based on comparatively simple algorithms (also mentioned as dispatching rules). Besides that, tour planning approaches, related to the Travelling Salesman Problem (TSP), are employed. Both of them now neglect the opportunity of dynamic transport carrier transfers between the vehicles during transport execution. Such transfers are increasingly investigated in other application areas like passenger transport or courier service. The results achieved here show significant reductions in delivery time and vehicle utilization but also indicate that the benefits of transfers depend highly on the characteristics of the system.

However, it is not clear whether the approaches already developed can be adapted to AGV system control. This article describes a heuristic approach, Modified Adaptive Large Neighborhood Search (MALNS), to control AGV fleets considering dynamic transfers. The results of generic test instances prove that the heuristic approach can identify transfers and their benefits. Limitations for the use in AGV systems are described.

The article has the following structure. Section 2 describes the concept of dynamic transfers. Afterward, results from literature represent the current state in AGV control and scheduling considering transfers from other vehicle systems (see Section 3). Section 4 presents the MALNS heuristic approach for AGV scheduling, considering dynamic transfers. In Section 5, experiments based on representative generic test instances demonstrate the heuristic application and the effect of transfers.

2 CONCEPT OF DYNAMIC TRANSFERS

The concept of dynamic transfers allows the vehicles of an AGV system to exchange transport carriers among each other multiple times during transport execution. An exchange of transport carriers is allowed at static located transfer points. The more transfer points are available; the higher is the flexibility of the system. The execution of transfers is not predefined. They are scheduled dynamically, depending on the system state.

Until now, the control of AGV systems has generally assumed that a transport request is executed by one vehicle. Figure 1 compares a common AGV dispatching approach (carriers are selected by shortest distance to the vehicles) to a scenario their transfers are allowed. In both cases, two transport carriers need to be transported by two vehicles with predefined start and end locations. On the left side, the vehicles directly transport one of the carriers each. On the right side, also each vehicle picks up a carrier. Afterwards, a transfer takes place and the carriers are transported to the drop off locations. The evaluation demonstrates a small reduction in delivery time (around 6%) and a significant reduction in vehicle driving distance (around 31%).

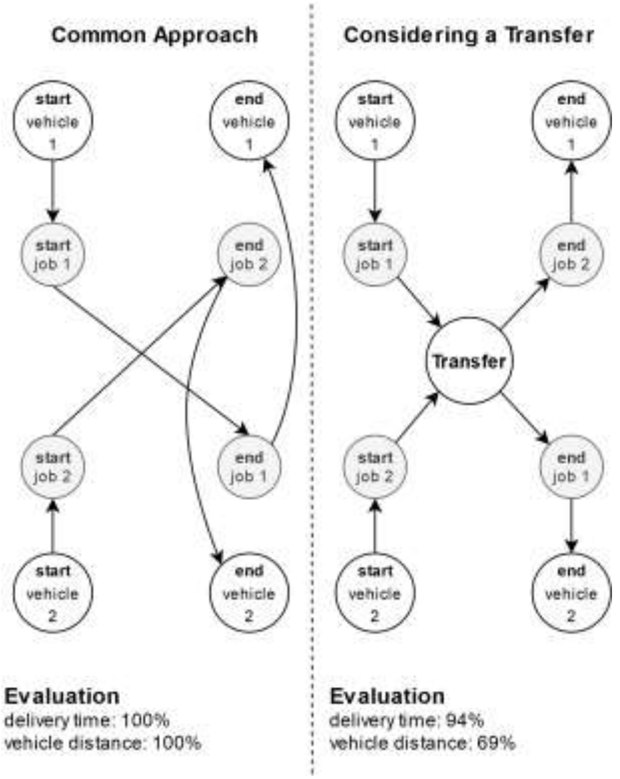

Figure 1. A basic example of dynamic transfers from simulation

The primary examples suggest that transfers can positively impact the performance of AGV systems. For planning problems with more vehicles, more transport requests, and more transfer points it is challenging to plan transfers and evaluate the effect due to the rapidly increasing number of possible combinations to create schedules. Therefore, algorithmic approaches are required to study the effect of transfers and to control AGV systems.

Various scenarios are possible to transport a request from the pickup point *(P)* to the drop off point *(D)* by the vehicles in an AGV transport system. Figure 2 provides an overview of the basic scenarios:

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- (Scenario A) a vehicle is carrying a load without any transfer,
- (Scenario B) the transport carrier is transferred *(T)* between two or even multiple vehicles, and
- (Scenario C) the transport carrier is deposited and picked up again.

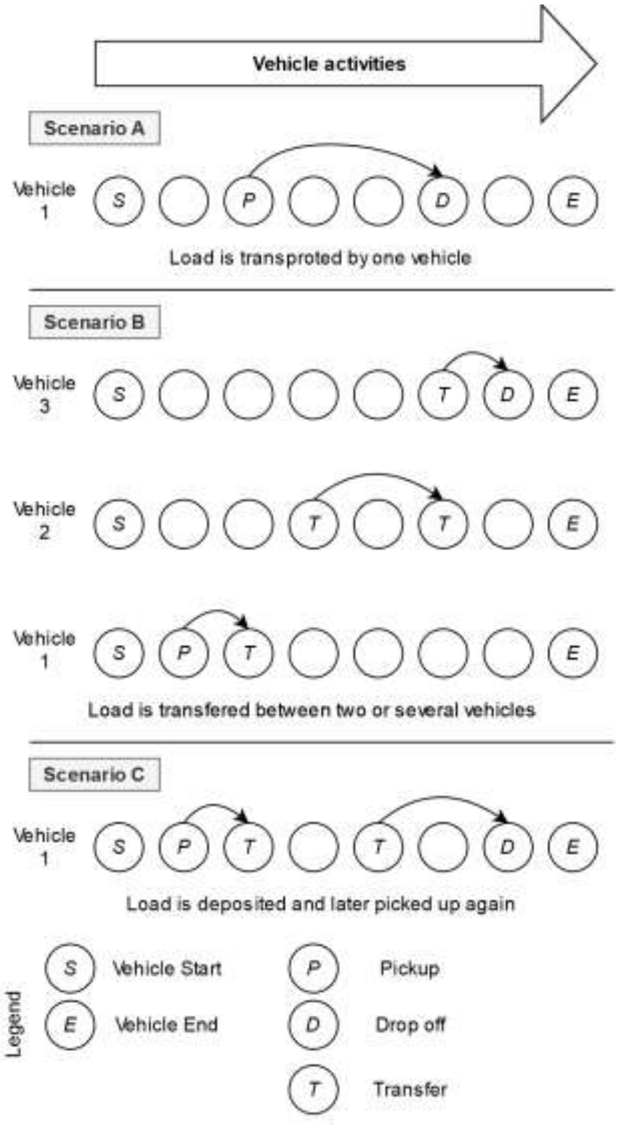

Figure 2. Transport scenarios [see QU12]

In general, transfers can be carried out by static transfer points where the transport carrier can be buffered or directly exchanged between vehicles. It is essential to ensure that the time sequence is kept for the moving transport carrier in both scenarios. A receiving vehicle is able to pick up the transport carrier just after it is dropped off at the transfer point. This requirement can lead to considerable waiting times for the executing vehicles.

The possibility to consider transfers significantly increases the flexibility of a vehicle-based transport system. This flexibility offers several advantages:

- *Objective:* Performance indicators like short delivery times, high throughput or low vehicle usage can be improved.
- *Constraints:* Better consideration of constraints for carrier transport (e.g. time windows for pick up and drop off) and vehicle usage (e.g. maximum ride time).
- *Characteristic:* The specific characteristics consider more effectively. These include, in particular heterogeneous vehicle fleets where, for example, speed, capacity, and the accessibility of handover stations vary.

So far, it remains unclear whether these advantages can be realized for AGV systems. Therefore, an algorithm is presented (see Section 4) in the following, which can be used to generate schedules taking into account dynamic transfers. Afterward, the results of the experiments (see Section 5) will show whether certain advantages can be confirmed.

3 CONTROL OF AGV FLEETS

3.1 COMMON APPROACHES

Following [SCH00], the control of an AGV system can be separated into three main processes: transport carrier-vehicle assignment, route selection, and traffic control. The assignment process assigns to each of the vehicles a set of transport jobs that need to proceed and defines the processing sequence. Routing determines the path for the vehicles to reach their next destination. Traffic control ensures driving with minimal conflicts with other vehicles and conflict resolution. This article is dedicated to the transport carrier-vehicle assignment process that is referred to as scheduling. Like in other publications in that field [QIU02, MOU17], it is assumed that routing and traffic management are planned independently since integrated planning of these three components is too complicated for real-time decision making.

The most common way to schedule an AGV fleet is to integrate comparatively simple algorithmic approaches like ‘select transport carrier at nearest location’ or ‘select transport carrier at the tool with maximum outgoing queue size’ [EGB84]. This way of AGV control is also known as dispatching. The selection of dispatching algorithms has a significant impact on fleet performance and is studied extensively for single-load [KLE96] and multiple-load [HO06] AGV systems. Based on these algorithms, some authors propose control systems using multi-criteria deci-

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sion-making [JEO01, BEN03]. Using dispatching algorithms instead of sophisticated scheduling approaches allows calculating scheduling decisions even for large vehicle fleets in a short time.

In contrast to this, AGV fleets can also be scheduled by approaches from the field tour planning and its underlying TSP. This model can be adapted for AGV control by the implementation of further constraints, which results in the so-called Vehicle Routing Problem (VRP), Pickup and Delivery Problem (PDP), or Dial a Ride Problem (DARP) [BER07]. Since these problems are NP-hard [PAR08], it is suspected that there exists no polynomial-time algorithm that efficiently solves these problems. As a result, they are generally not appropriate for the real-time control of AGV systems.

In order to calculate solutions, either exact or heuristic algorithms, can be employed. Exact algorithms, like Branch and Bound, are applied to find solutions and prove them to be exact (e.g. the minimal solution for a problem), but they are strongly restricted in problem size. Heuristic approaches (e.g. Neighborhood Search and Simulated Annealing) are used to calculate solutions for more extensive problem instances than exact algorithms, but there is no measure for solution quality [MOL17]. Results from the literature demonstrate that such approaches can lead to performance benefits. [LEA05] investigated different exact and heuristic approaches to solve the AGV scheduling problem. The author demonstrated that dynamic scheduling outperforms simple dispatching approaches. The authors of this article discussed scheduling for multiple load AGV using an Adaptive Large Neighborhood Search (ALNS) heuristic in [BOD19].

3.2 TRANSFER APPROACHES FROM OTHER APPLICATIONS

Transfers are not considered in the context of the AGV fleet controlling so far. Therefore, they are not referred to or explicitly excluded in literature. However, they are increasingly considered for problems in other transport systems, which can be modeled by the VRP and related problems. These application fields include passenger transport, such as pupils or disabled persons [MAS14]. Also, courier services and freight forwarding agencies are fields of application for the transfer of goods [PET11, QU12].

Generating a schedule considering transfers (T) is challenging, since the generalized problems VRP-T, PDP-T, and DARP-T are also NP-hard to solve. Table 1 provides an overview of modeling and solution generation techniques. Exact approaches like Branch and Cut or standard solvers (e.g. CPLEX) are utilized to generate solutions for small problem instances with up to 4 transport jobs. To investigate more extensive problem instances, approximate techniques based on Local Search (like Large Neighborhood Search or ALNS), Metaheuristics (like Genetic Algorithms) are conventional.

By applying the algorithms to static test cases and also real transport systems, it was found that the use of transfers could lead to considerable improvements in fleet efficiency (e.g. 12% in [DEL13] or 8% in [MAS14]). The level of improvement depends on the characteristics of the transport system [MIT06]. A comprehensive investigation of the influencing factors is still pending. Furthermore, the majority of the authors assume planning tasks, which allows calculation times of several minutes and more. A comprehensive investigation of the real-time capability required for AGV operation is also still outstanding.

Table 1. Modeling and solution generation

Author	Model	Solution generation
[COR10]	PDP-T	Exact by Branch and Cut
[DAN18]	PDP-T	Heuristic by Large Neighborhood Search; Genetic Algorithm
[DEL13]	DARP-T	Heuristic by Constraint Propagation
[MAS14]	DARP-T	Heuristic by ALNS
[MIT06]	PDP-T	Heuristic by Local Search
[OLI18]	PDP-T	Exact by standard solver; Heuristic by ALNS
[PET11]	PDP-T	Heuristic by ALNS
[QU12]	PDP-T	Heuristic by ALNS
[RAI14]	PDP-T	Exact by a standard solver

The literature results demonstrate that the ALNS heuristic is primarily applied to the planning of dynamic transfers. It enables a high solution quality, even for large problem sizes. Therefore, this approach will be the focus of the following considerations. A direct application to the application case AGV is not possible. For this purpose, adaptations are necessary, which are presented in the following section. The adaptions result in a modified approach that is called Modified Adaptive Large Neighborhood Search.

4 HEURISTIC APPROACH

4.1 GENERAL ADAPTIVE LARGE NEIGHBORHOOD SEARCH

The ALNS is based on the principle of removing transport requests from a schedule and inserting them again until a termination criterion reaches. The iterative redesign of the schedule is intended to improve an objective value.

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Several heuristics, so-called sub-heuristics, are used to remove and insert transports. Adaptive weights select these heuristics based on their performance during the optimization process. This attribute makes the ALNS adaptive. Since the ALNS integrates the Simulated Annealing concept, it allows in an early stage of optimization the acceptance of worse solutions for further investigation. Thus, the search is diversified and getting stuck in local best solutions can be overcome.

In general, the ALNS is executed in two phases to generate schedules considering dynamic transfers. While in phase two, transfers are allowed for reinsertion, they are prohibited in phase one. The idea is to start the improvement phase two with a valid and preferably good solution for further improvements since the investigation of transfers is computationally intensive. Phase one starts with an empty schedule and a list of pending transport tasks. In the first step, the transport jobs are added to the schedule by their effect on the cost to the overall schedule. In this way, an initial solution generates in a short time. The first improvement phase takes the best solution from the initial solution phase.

Several hyper-parameters control the ALNS heuristic. These parameters are a maximum amount of requests that are allowed to remove from the schedule, an acceptance threshold for the Simulated Annealing procedure, a probability to consider transfers in phase two and the distribution of calculation time between phase one and phase two.

The ALNS heuristic has already been discussed in connection with scheduling vehicle-based transport systems considering transfers [MAS14, OLI18, PET11, QU12]. In addition to that, for other vehicle routing problems like freight transportation, the ALNS also allowed the identification of transfers [GUA16]. The previous results show that the ALNS robustly identifies transfers for real transport systems. Based on these results, it was selected to investigate the adaption to the AGV application. The relevant modifications are discussed in the following section.

4.2 MODIFIED ADAPTIVE LARGE NEIGHBORHOOD SEARCH

The modifications of the ALNS approach for the adaption to AGV scheduling concern the representation of the underlying optimization problem (referred to as modeling) and the generation of the solution by the optimization algorithm. Both categories are described in more detail below (see Section 4.2.1 and 4.2.2). Finally, a detailed overview of the entire optimization process is given (see Section 4.2.3).

4.2.1 MODELING

To generate schedules for an AGV system, the characteristics of the transport tasks and the vehicle system need to be considered by the heuristic approach. The properties of the AGV system are modeled in a generic way to formally describe the underlying assumptions of the approach and to allow the investigation of a wide range of AGV applications by parameterization. In this way, the MALNS allow general conclusions which do not relate to a single system.

Transport tasks are modeled as a pair of start and end locations that need to be visited in specific time windows. The locations responding to a transport task do not need to be visited by the same vehicle. Nevertheless, consistent flow from a start location, possibly passing several transfer locations, to an end location must be ensured. Every transport needs transport capacity on a vehicle. This demand is not divisible and the transport load must be transported by one vehicle at a time. Transport tasks can be executed by each vehicle with sufficient capacity that can visit the pickup and the drop off location in the respective time windows.

Transport vehicles are characterized by distinct start and end locations. Even if a vehicle does not carry out transports, it needs to drive to its final destination. In addition, the vehicles are modeled by vehicle capacity, vehicle speed, and vehicle handling time. These parameters can be selected for each vehicle individually. Hence, the modeling of heterogeneous vehicle fleets, where the vehicles have different properties, is also possible.

Predefined locations determine transfer stations. They have no capacity limit to buffer transport carriers. Also, there are no time limits to visit the transfer point. Only the precedence constraint needs to be ensured, where the sending vehicle must leave the transfer point before the receiving vehicle can pick up the carrier.

The minimization of vehicle activities for driving and handling was selected as the objective. If transport tasks can be carried out with less effort, this may result in positive effects on vehicle utilization and achievable throughput.

4.2.2 SOLUTION GENERATION

AGV control is a real-time planning problem. Due to the continually changing system state, the generation of a new schedule is regularly triggered. A sufficient plan needs to be generated within seconds. Also, solution generation needs to consider the characteristic of the planning problem of scheduling scenarios in AGV systems. Hence, the functions for creating modified schedules, mentioned as sub-heuristics, are adjusted to the AGV application.

Contrary to the standard ALNS approach, where a limit of iterations predefines termination, the MALNS heuristic terminates by a time limit. Thus, real-time control tasks can be investigated, and the effect of the available calculation time on the achievable solution quality can be examined.

The essence of the approach is the generation of new schedules by the application of several sub-heuristics. To improve the schedule, transport jobs are selected to be removed from and reinserted. In the following, the adapted sub-heuristics for removing and inserting transport requests are explained in more detail. To select a transport job to be removed the sub-heuristics:

- ‘remove a random job’,
- ‘remove the job that has the longest time waiting before pickup’,
- ‘remove job with longest transport time’,
- ‘remove job with longest delivery time’ and
- ‘remove all jobs of a vehicle’

are implemented. These sub-heuristics are selected because they lead to a combination of randomized selection and the specific selection of cost-intensive transport jobs. In this way, the search is both diversified and transport jobs with a particularly high optimization potential are individually selected. There is a high potential for optimization if a transport request is carried out over a long distance or if the transport carrier is waiting for a long time before it is picked up for the first time. For the selection of specific jobs, an initial evaluation is carried out. The difference in costs between the schedule with the job and without the job is evaluated for each job. In the last case, all jobs that are transported by a vehicle will be removed. The selection does not consider whether it is a direct transport (without transfer) or a partial transport created by a transfer. This allows transferring a carrier multiple times.

The removed jobs will be reinserted. Therefore, all transport jobs will be evaluated with respect to all valid insert positions for pickup, drop-off, and if necessary, one transfer. Afterward, it is possible to select for each job the best insert position that increases the cost of the overall schedule and evaluate the cost increase between the minimum cost insert position and the other insert positions. A transport job will be selected using the sub-heuristics:

- ‘insert a random job’,
- ‘insert one of the least cost jobs’,
- ‘insert the least cost job’ and
- ‘insert the job with the fastest increasing cost'.

Based on the selection of a transport job by these sub-heuristics, the selected transport job will be inserted at its minimum cost position. Afterward, the evaluation will start again for the remaining jobs. The combination of these sub-heuristics allows the diversification of the search procedure and the evaluation of solutions with low costs.

In phase two of the optimization process, in each iteration, it is chosen randomly if transfers will be considered or not. If a transfer needs to be considered, a transfer node with a short detour is chosen. The transport job is divided into two parts. First, the pickup tour and afterward, the drop off tour will be inserted to the schedule using the specified insertion sub-heuristics, ensuring a valid sequence of vehicle arrivals at the transfer node.

4.2.3 DETAILED DESCRIPTION OF THE OPTIMIZATION PROCEDURE

The MALNS algorithm consists of two phases, working as specified in Figure 3. In phase one and phase two, the algorithm starts with an initial solution s. The objective value of this solution is considered as actually best-known solution s_{best}. Until the termination criterion (a specified time limit) is not met, a local search is proceeding to evaluate the search space. Therefore, the described sub-heuristics (see 4.2.2) are employed to remove and reinsert a number of transport jobs q from and to the schedule.

Since this process is time-consuming, parallel multi-thread techniques are implemented. When the specified number of threads t$h \in TH$ is started, the algorithm waits to complete all threads. Each thread uses a local copy of the schedule $s_{local,th}$ that is actually under investigation and performs modifications individually. These modifications are the selection of the number of requests that need to be removed, the removing sub-heuristic, the inserting sub-heuristic and the consideration of transfers.

The created schedule of each thread will be appended to the set of schedules S_{global}. These schedules are evaluated iteratively using a Simulated Annealing approach. This metaheuristic allows in an early stage of the optimization that, compared to the current best-known solution s_{best}, also worse schedules can be selected for further investigation. This is done by the $accept$ function. However, if a new overall best solution s_{best} is found, this solution will replace the former best-known solution and it will be accepted for the next iteration of the local search procedure.

The performance of the sub-heuristics is evaluated during computation and leads to an update of the sub-heuristics weights. These weights control the probability that they will be chosen. Sub-heuristics that achieve better results are thus utilized more often.

As already described (see Section 4.1), there are several hyper-parameters to guide the optimization process. The setting of these parameters are discussed in Section 5.1.2.

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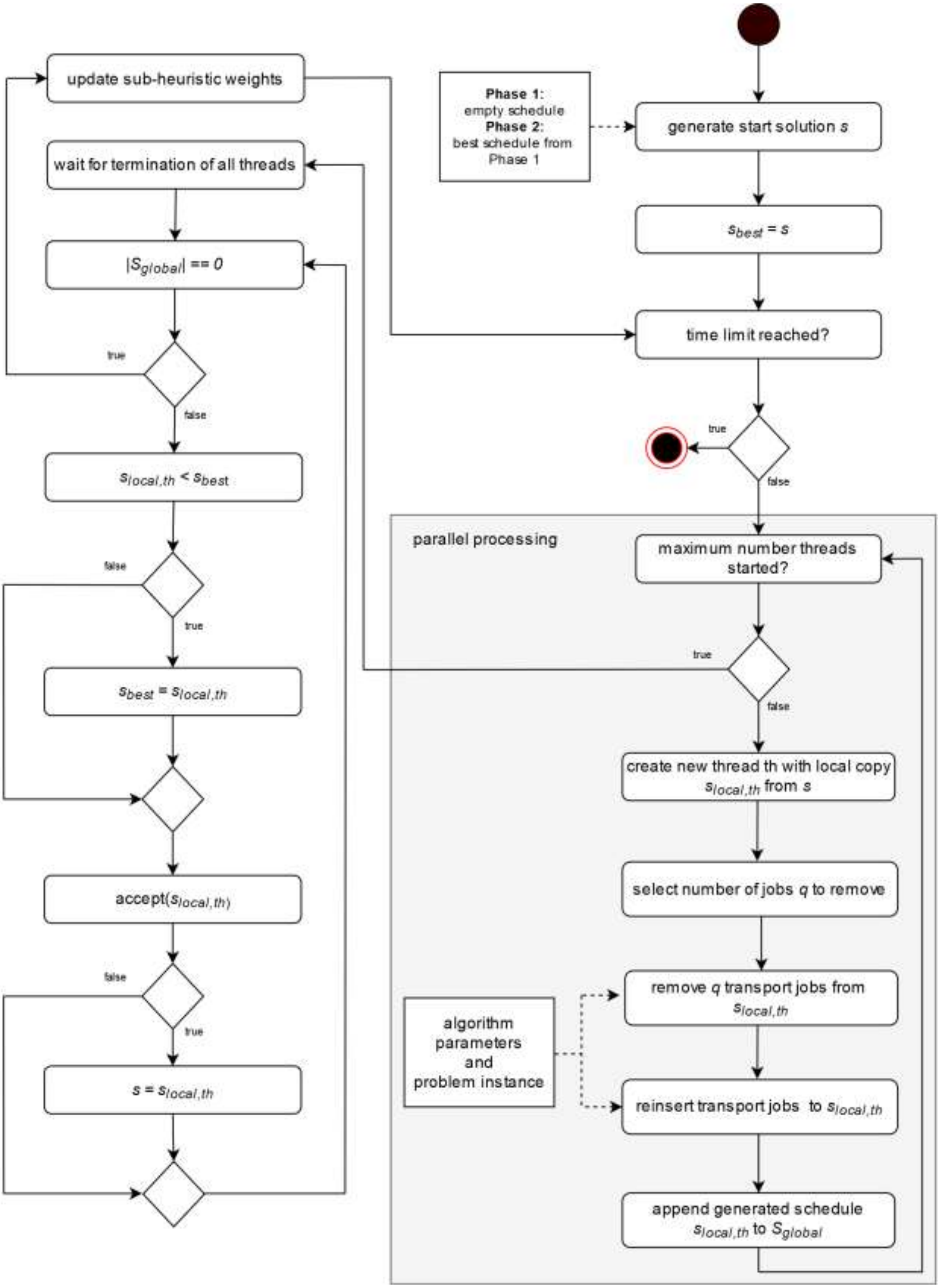

Figure 3. MALNS Heuristic Procedure

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5 COMPUTATIONAL EXPERIMENTS AND RESULTS

5.1 PRELIMINARY CONSIDERATIONS

5.1.1 EXPERIMENT SETTING

Experiments with generic test instances adapted to the AGV use case evaluate the MALNS heuristic. They provide an abstract representation of scheduling scenarios in AGV systems. Hence, the achieved results allow general conclusions that are not related to a single system.

The test instances structure is as follows: Transport jobs are modeled by start and endpoint, time windows for loading and unloading and capacity demand. Vehicles are characterized by speed, capacity, start and end points, and handling time. Transfer points are also considered. The respective locations of these points are located randomly within a grid of 50x50 meters. The variation of the other parameters was also randomly within fixed limits.

The number of possible combinations for a schedule increases exponentially with problem size and hence computational times for searching the complete solution space. For this article, a variation on four problem sizes (see Table 2) addresses this subject. The calculation time limit as the termination criterion for the MALNS varies between 3 seconds, 30 seconds, and 300 seconds. Therefore, the results indicate if transfers can be considered for operational AGV systems and which potentials remain by improvements in hardware and adaptions of the MALNS. For each of the in Table 2 summarized experiments, 100 generic test instances are created and solved.

Table 2. Defined Problem sizes

Exp. Identifier	# of transport jobs	# of vehicles	# of transfer points
4_2_4	4	2	4
8_4_4	8	4	4
12_6_4	12	6	4
16_8_4	16	8	4

In general, there is a tradeoff between the use of the full computation time for the generation of schedules without transfers and spending a part of the time to identify schedules with transfers. Because the amount of time searching for transfers could result in better solutions without the consideration of transfers. Hence, all instances are solved two times. In one trial with the consideration of transfers and one trial without the consideration of transfers. A transfer is only accepted for the evaluation if the result improves the objective value of the solution without a transfer.

The experiments are conducted on a desktop PC with a i5-3470 CPU running on 3.2 GHz and 4 cores. The heuristic was implemented in C++.

5.1.2 MALNS HYPER-PARAMETER SETTING

There are four essential heuristic parameters. These include the threshold for the acceptance of new solutions of the Simulated Annealing process, the maximum percentage of transport requests that may be removed to generate a new schedule, the probability that transfers are considered in phase two, and the distribution of the computing time between phase one and phase two.

A systematic screening has shown that the parameters significantly influence the identification of solutions that benefit from transfers. With an acceptance rate of 75%, a limit of 50% for the removal of requests, 75% for the consideration of transfers in phase two and distribution of the computing time from 1/3 to phase one and 2/3 in phase two, the highest number of solutions containing transfers could be achieved. Therefore, they serve as a reference for the following investigations.

5.2 IDENTIFICATION OF TRANSFERS

The application of the MALNS heuristic with a computation time of 30 seconds for solving the described problem instances lead to following results (see Figure 4): In average around 5% of the investigated instances are improved by the consideration of a dynamic transfer, instances with a low number of transport jobs and vehicles benefit in more cases (around 11%) by transfers and problem instances with a higher number of transport jobs benefit less or even not. On average, a transfer improves the objective value of a schedule by 2% and in maximum by 7%.

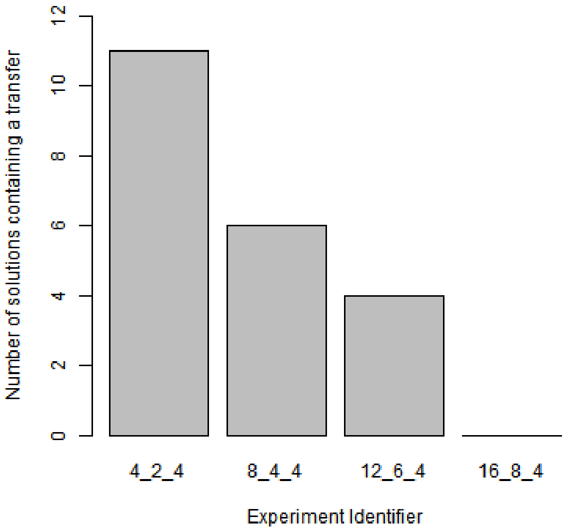

Figure 4. Number of identified transfers out of 100 generic test instances with 30 sec calculation time limit

The results demonstrate that the MALNS heuristic identifies transfers for generic planning problems in AGV systems. Besides that, the computation of results is possible in an affordable amount of time.

However, by increasing problem size, the number of identified transfers decreases strongly. For further investigations, additional experiments are carried out with a variation in calculation time. The results are summarized in Table 3.

Table 3. Evaluation of Transfers related to heuristic settings and problem size

Calculation Time Limit

	Exp.Identifier (see Table 2)	3 s	30 s	300 s	
Problem Size	4_2_4	10	11	11	# T
		2.3%	2.6%	2.0%	Avg
		5.8%	7.3%	5.8%	Max
	8_4_4	2	6	7	# T
		1.5%	0.8%	0.9%	Avg
		1.8%	2.2%	2.5%	Max
	12_6_4	0	4	5	# T
		-	0.5%	1.0%	Avg
		-	1.3%	4.0%	Max
	16_8_4	1	0	1	# T
		2.4%	-	0.6%	Avg
		2.4%	-	0.6%	Max

Concerning the average number of identified transfers, there are two main effects: The number of transfers is rising for an increasing calculation time and falling with increasing problem size. For small-sized problem instances with only 4 transport requests and 2 vehicles there is no significant difference between the time limit of 3 seconds, 30 seconds and 300 seconds. For problem instances with 8 or 12 transport jobs and 4 or 6 vehicles, there is a trend that an increasing amount of computation time from 3 seconds to 30 seconds results in a higher number of transfers that can be identified. A change from 30 seconds to 300 seconds shows just a minor effect. For the next bigger category of instances with 16 transport requests and 8 vehicles, no reliable conclusions can be drawn, since the number of identified transfers is too low.

Even with a calculation time limit of 300 seconds, the number of transfers is falling with increasing problem size. It remains unclear if this effect evolves because there is no need for transfers in large problem instances. For instance, because there is always a vehicle that can transport a request on its way from the vehicle start location to the vehicle end location without significant detours. Or alternatively, if the heuristic approach is not capable of identifying transfers.

The number of schedules generated in phase two of the MALNS decreases strongly as the size of the problem increases (see Table 4). That indicates that the computational resources are not sufficient for the scheduling of larger fleets. This will be a subject of further investigation.

Table 4. The average number of schedules generated in phase two of the MALNS by problem size and calculation time limit

Calculation Time Limit

	Exp.Identifier (see Table 2)	3 s	30 s	300 s
Problem Size	4_2_4	357	3633	35855
	8_4_4	51	463	4571
	12_6_4	15	106	1025
	16_8_4	8	37	329

5.3 EFFECT ON PARALLELIZATION

To improve the MALNS approach regarding the computation time, parallel processing was implemented to perform schedule modifications (see Figure 3). In order to examine the effects of parallelization, the results of the experiments utilizing four parallel threads were compared to generated results with only one thread.

The results are summarized as an average improvement from one to four parallel threads in Figure 5. On the y-axis, the heuristic settings are listed as [calculation time w – with or wo – without transfer consideration]. The x-axis shows the problem size. An average of all experiments shows a slight improvement of 0.5% by multi-threading. A maximum improvement of 1.5% was achieved for the category of problem instances with 16 transport requests and 8 vehicles.

The improvement depends mainly on the combination of calculation time and problem size. With a large problem size and short calculation time, improvements of more than 1% can be observed. If the problem size is small, slightly worse results are also possible. Scenarios, where transfers are taken into account benefit stronger on parallelization. This improvement is due to the significantly higher number of possible combinations to generate schedules and explains why the effect decreases with increasing calculation time.

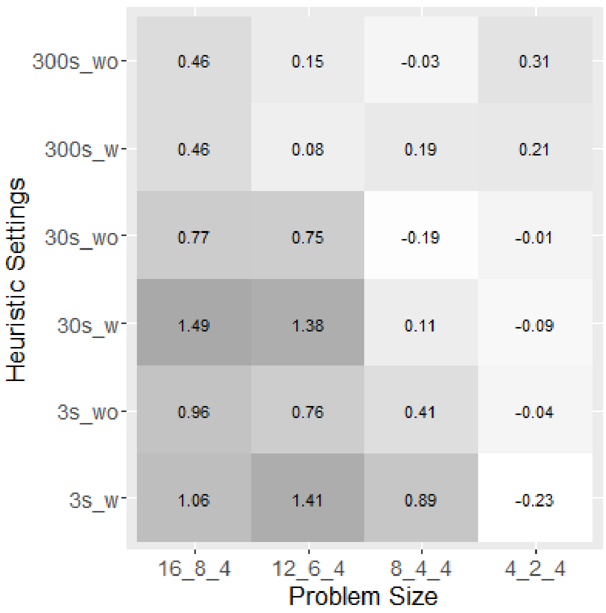

Figure 5. The average improvement of the objective value between parallel and non-parallel computation

5.4 COMPARISON OF MALNS IN THE CONSIDERATION AND THE NEGLECTION TRANSFERS

The evaluation of transfer operations is computationally expensive. This effort could also be spent on further optimization of the solution while neglecting transfers. On average, a better objective value could be reached in that way.

To evaluate this effect, Table 5 summarizes the average difference in percent between the consideration and the neglect of transfers in the MALNS optimization process. The following concludes: For problem instances with small problem size, the heuristic considering transfers improves overall the variant without transfers. When the problem size increases and the calculation time decreases, the heuristic without transfers results in general in better schedules. For a problem instance size of 8 transport requests, 4 vehicles, and 4 transfer points, the result is indifferent in the case of a 30 seconds calculation time limit.

The results suggest that for controlling an AGV system in general, two solutions should be calculated. One solution is taking into account and one solution is neglecting transfers. The best solution should then be executed. So, transfers will only occur if they are meaningful.

Table 5. Average deterioration compared to the heuristic while neglecting transfers in %

	Calculation Time Limit		
Problem Size	3 s	30 s	300 s
4_2_4	-0.3	-0.3	-0.2
8_4_4	1.1	0.1	0.2
12_6_4	2.9	1.2	0.6
16_8_4	1.4	1.8	1.0

6 CONCLUSION AND OUTLOOK

In this article we proposed, a MALNS heuristic to schedule modest AGV fleets under the consideration of dynamic transport carrier transfers.

The results of the experiments demonstrate the identification of schedules considering dynamic transfers by the MALNS approach and generic randomized test instances. On average, 5% of the investigated instances benefit from the consideration of transfer operations. These transfers have a significant influence on the sum of costs for vehicle activities like driving and handling. The average improvement is around 2%.

However, a small increase in problem size to 8 vehicles and 16 transport jobs demonstrates the limitations of the approach. Since the number of transfers that could be identified even with a time limit of 300 seconds strongly decreases.

For further research, the algorithm will be applied to evaluate the benefit of transfers in AGV systems in more detail. Typical system characteristics, like the regional distribution of pickup and delivery locations, as well as transfer points, are supposed to impact the possibility that a transfer can improve the schedule. Also, a material flow simulation study taking into account representative AGV systems like a warehouse will be carried out to test the approach in dynamic systems.

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