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DISPATCHING AUTOMATED GUIDED VEHICLES CONSIDERING TRANSPORT LOAD TRANSFERS

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ABSTRACT

The paper presents a dispatching algorithm for Automated Guided Vehicle systems that considers transport load transfers between vehicles to improve system performance. Transfers are primarily neglected so far to control Automated Guided Vehicle systems. Nevertheless, applications from other domains like courier services demonstrate an efficiency increase by considering transfers. The concept of transfers allows an exchange of transport items between vehicles during transport execution. Therefore, a transport job is divided into sub-transport jobs executed by different vehicles. With our algorithm, transfers are planned ad-hoc depending on the current system status in real-time. The objective is to improve system performance by decreasing vehicle utilization to yield higher throughput. A case study examines the algorithm using a material flow simulation study. As a key result, the simulation study revealed that vehicle utilization could be reduced up to 4 % for the same throughput when transport load transfers are allowed.

1 INTRODUCTION

Automated Guided Vehicles (AGV) allow automation of transportation tasks in production and logistics systems. They are common in many industries like distribution centers, container terminals or semiconductor production (Fazlollahtabar and Saidi-Mehrabad 2015).

So far, dispatching AGV is based on the premise that a single vehicle executes an allocated transport job. In contrast, this work evaluates a concept where an exchange of transport loads between the vehicles at dedicated transfer stations becomes possible: transport load transfers are planned ad-hoc considering the current system state (e.g., vehicle positions and running transport jobs) by a central control unit that assigns the transport jobs to the vehicles. To execute a transfer operation, a vehicle is directed by the dispatcher to buffer a transport load at a predefined transfer location. Subsequently, a receiving vehicle continues the transport. This flexibility in task assignment could help reduce vehicle tour lengths by enabling synergy effects, e.g., combining transports with similar destinations. However, assigning transport jobs to vehicles becomes more complex, as there are far more options for the transport job assignment.

As intended to be applied in the intralogistics context, the work is motivated by applications from other domains such as passenger transportation or courier services: the additional flexibility in task assignment through transfers enables higher system performance (see Section 2). However, it also became obvious that transfer operations require additional effort, which has to be compensated by possible synergy effects. We conclude that the benefit of transfers depends on the characteristics of the transport system (e.g., handling time). It also remains unclear if and how transfers can be planned in real-time to control AGV with its specific characteristics (e.g., limited capacity).

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Two central problems must be solved to realize (and benefit from) the concept of transfers for AGV systems: (1) transfer locations must be located in the layout, (2) for task assignment, transport jobs must be divided into sub-transport jobs to achieve benefits. We will place transfer locations randomly and focus on the second aspect first since we want to demonstrate that transfers lead to an improvement in system performance. Optimization of the position of transfer locations is the subject of future research and can lead to an even higher benefit.

So, to solve the task assignment problem, this paper presents a dispatching algorithm for AGV systems considering transport load transfers. We will demonstrate:

- that real-time control of an AGV fleet considering transport load transfers is possible,
- that significant performance improvements can be achieved, and
- that the benefit of transfers depends on the characteristics of the transport system.

We evaluate the algorithm by test instances and a material flow simulation study.

The remainder of the paper is structured as follows. Related work is focused on in Section 2. Section 3 describes the dispatching algorithm. Test instances examine the algorithm in Section 4. A case study based on a material flow simulation study is reported in Section 5. Section 6 concludes.

2 RELATED WORK

Based on detailed literature research, we note that transport job splitting via transfers has not yet been considered for AGV dispatching in the intralogistics domain. So it remains open if the benefits reported from other domains (see the introduction and the following) can also be realized in the intralogistics domain and hence how they must be realized. However, it is quite reasonable to assume that the transfer of transport loads can achieve synergy effects concerning the destinations of other transport jobs or even a parking position of other vehicles. Thus, they might help to increase the performance of an AGV system.

In order to realize transfers for AGV systems, we assume that vehicles can buffer transport loads at predefined transfer locations. There, the load is later picked up by another vehicle. The focus of our work is to define and assign sub-transport jobs to the vehicles in such a way that the transfer locations are used for transfers in order to achieve benefits. Therefore transport jobs can be divided into any number of sub-transport jobs and hence an algorithm for appropriately dispatching the AGV is needed.

Dispatching determines how transport tasks (pick-up or drop-off of transport jobs) are assigned to the vehicles and how to proceed with empty vehicles. In detail, it defines in which sequence and when the AGV will execute transport tasks. Dispatching has to consider the characteristics of the transport system, which primarily includes the properties of vehicles (e.g., capacity), transport jobs (e.g., position of start and end locations) and the path network (e.g., distances between locations). Following De Ryck, Versteyhe, and Debrouwere (2020), current systems are controlled by a central control unit that manages the entire vehicle fleet. This allows taking all relevant information of the current system status into account and hence act accordingly. On the other hand, applying central controlling units is quite challenging, as dispatching in real-time in connection with stochastic effects like failures of vehicles or new transport jobs is required. Usually, only a few seconds are available for the calculation, even if vehicle fleets with several AGV and numerous transport jobs must be considered.

To handle the task of dispatching, mathematical models are applied. In this context, e.g., the Pickup and Delivery Problem (PDP) can represent the assignment of transport jobs to vehicles. It allows calculating schedules that include the execution of all pending transport tasks. The mathematical model is considered NP-hard, which means that there is no efficient algorithm providing exact/proven optimal solutions in polynomial time (Toth and Vigo 2002). Thus, approximate solution techniques (called heuristics) are necessary to generate solutions.

Roughly, there are two types of heuristic approaches for AGV dispatching applied. Those that generate a plan with all outstanding transport tasks and those that select only the next task to execute. Metaheuristics (e.g., Simulated Annealing) are mainly used for the first category. They allow high solution quality with the downside of being constrained in problem size (e.g., number of vehicles) (Le-Anh 2005) because they take many iterations to improve. Since transfers make the computation of solutions even more demanding, such approaches are excluded from our further considerations. Algorithms of the second category try to generate good results based on criteria that are fast to evaluate. Egbelu and Tanchoco (1984) provide an overview for such criteria, with the result that e.g., the selection of transport jobs by nearest location to the vehicle provides performant results.

Most literature focus on AGV systems with a capacity of one transport load. Dispatching algorithms for so-called multiple-load AGV are discussed in Nayyar and Khator (1993), Ho and Chien (2006), Ho and Liu (2006) and Li and Kuhl (2017). In this case, a partially loaded AGV also needs to be considered for dispatching. Here, pick-up processes can be preferred to make use of the additional capacity.

Even though there are possible approaches, so far, in the intralogistics domain, they have not been considered for running AGV systems with transfers.

In other domains like passenger transport or courier services, transfers are more focused in scientific literature and practical application. Although the systems differ significantly in their requirements, they can still demonstrate how schedules can be calculated and whether a benefit can be achieved. In order to calculate corresponding schedules, authors often refer to a variant of the PDP, the Pickup and Delivery Problem with Transfers (PDP-T). The model can be found in Cortés, Matamala, and Contardo (2010), Rais, Alvelos, and Carvalho (2014) and Sampaio, Savelsbergh, Veelenturf, and Van Woensel (2020).

Coltin (2014) investigates a system of mobile service robots. The author provides various solution techniques like the exact solution by a standard solver and heuristic techniques to define schedules with all open transport jobs. He shows that transport load transfers between vehicles can achieve performance improvements compared to schedules neglecting transfers. The improvements are mainly the result of reduced penalties for exceeding time windows for the execution of transportation tasks. The focus on time windows is more in line with passenger transport applications and less important for AGV dispatching. An analysis of the influence of the system characteristic and how the algorithms perform compared to standard dispatching approaches for AGV remains open.

Cortés, Matamala, and Contardo (2010) take a Branch and Bound algorithm to generate optimal schedules for passenger transport systems. Already for systems with only two vehicles, this takes several minutes. The approach is therefore not appropriate for real-time dispatching.

A Metaheuristic approach called Adaptive Large Neighborhood Search (ALNS) is studied in Petersen and Ropke (2011) and Masson, Lehuédé, and Péton (2014). Masson, Lehuédé, and Péton (2014) investigates a system for passenger transport by test instances with up to 8 vehicles and 96 requests with a computation time limit of 10 h. Compared to the best-known solution neglecting transfers, they achieved cost (effort for driving and handling) improvements up to 9.7 % and 3.5 % on average. Petersen and Ropke (2011) demonstrates improvements by transfers for a distribution logistics scenario. They create schedules for several hundred transport jobs with a time limit of 90 min.

To sum up, the algorithms are applied with a great time limit suitable for offline problems. Thus, they can not be applied for real-time control of an AGV system.

Problem characteristics influence on courier services is studied in Mitrović-Minić and Laporte (2006). They demonstrate that improvements by transfers are related to the characteristic of the system (e.g., location of pick-up and delivery locations). For AGV systems, a detailed analysis on which system characteristics benefit from exploiting synergies by transfers is still open.

In summary, dispatching AGV fleets is a challenging task due to the complexity of the planning problem. The consideration of transfer operations adds another level of freedom that makes it even more challenging to generate solutions. Currently, in the intralogistics domain, transfers are neither considered for AGV systems nor are there suitable algorithms for real-time dispatching available.

In contrast to previous work, we will present a dispatching algorithm that assigns transport jobs with limited computational effort and considers transfer operations. The algorithm extends known dispatching approaches for AGV and adapts it to evaluate the application and possible benefits in the intralogistics domain. We will show that our algorithm allows real-time dispatching and an improvement of relevant system performance indicators. The algorithm is described in the following section (Section 3).

3 DISPATCHING ALGORITHM

The dispatching algorithm integrates the search and definition of sub-transport jobs by transfer operations as an additional procedure (*transfer procedure*) to a standard dispatching algorithm for multiple-load AGV (Ho and Chien 2006). The idea is to achieve synergy effects focusing on the current system status (e.g., running transport jobs). Thus, transport costs (measured in time for driving and handling) will be reduced to decrease vehicle utilization and yield higher throughput.

The transfer procedure will be carried out when a vehicle loaded with transport items enters a predefined transfer location coincidentally on its path to another location (e.g., a drop-off location of a running transport job). The transfer procedure then iteratively defines sub-transport jobs starting from the transfer location and tries to assign them to other vehicles. The new assignment will be processed if a relevant cost advantage can be achieved. The receiving vehicle will be directed to pick-up the transport load at the transfer location as the next task. This helps to ensure that the expected benefits can be realized and avoids starvation of transport loads at the transfer location.

In contrast to common heuristics discussed in the literature, like the ALNS heuristic, the evaluation of potential transfer operations is based on a small subset of transport jobs. We only consider transport loads moved by the vehicle at the transfer location and receiving vehicles with available capacity. All other options like transfers at other transfer locations or the influence of pending transport jobs are neglected. This significantly reduces the computation time and allows us to control AGV in real-time.

The complete dispatching algorithm is described in Figure 1. In the following, the general assignment of transport jobs and the extension by the transfer procedure are described.

We take the *pick-up first-shortest distance* strategy as the approach for the overall assignment of transport jobs. Every time a vehicle completes a task and open tasks remain, a *task-determination problem* is solved. Here the vehicle prefers to pick-up tasks if there are still open tasks in the system and free capacity. If there is more than one load waiting, the *load-selection problem* takes the longest waiting transport load. In the other case, the *delivery-dispatching problem* is carried out. The load with the shortest distance to the drop-off location will be selected from all transport loads running at the vehicle. Based on this assignment, vehicles are routed to the following location specified in their schedule. Along the way, they visit several waypoints, some of them specified as transfer locations. The transfer procedure is carried out when a vehicle enters such a location.

The idea is to evaluate the possibility of a transfer for the transport jobs on the vehicle. For this purpose, options are evaluated where a transport load is left at the transfer location and carried on by another vehicle. If a cost reduction of the current schedule can be achieved, the transfer will be executed. As input, the algorithm (see algorithm 1) takes an initial solution s representing the current schedule of all vehicles, including vehicle capacities and current positions. Further inputs are, a set of vehicles K to evaluate for transferring, the vehicle kt at the transfer location and a threshold for cost improvements $thres$. Transfer operations are accepted only if the expected cost improvement is greater than this threshold. Since we do not consider pending transport tasks, there is a risk that a transfer has a negative influence. So, we consider only transfer operations with a high chance of improving the overall system performance.

The algorithm starts by initializing a set of requests TL that are carried by vehicle kt available for a transfer operation, evaluating the costs of the overall schedule as the current best solution cost c_{best} and defining a copy of the schedule s' to manipulate. In the following, each request tl in TL is evaluated for an exchange to another vehicle k in K. Therefore in each iteration request tl is removed from s' and inserted for vehicle k. If a solution is found that improves c_{best} by more than a threshold $thres$, s is replaced by s' as new best solution. Otherwise, the function rejects s'. We take the first improvement found as stop criteria for evaluating the transport task tl. The routine evaluates the remaining transport tasks in set TL.

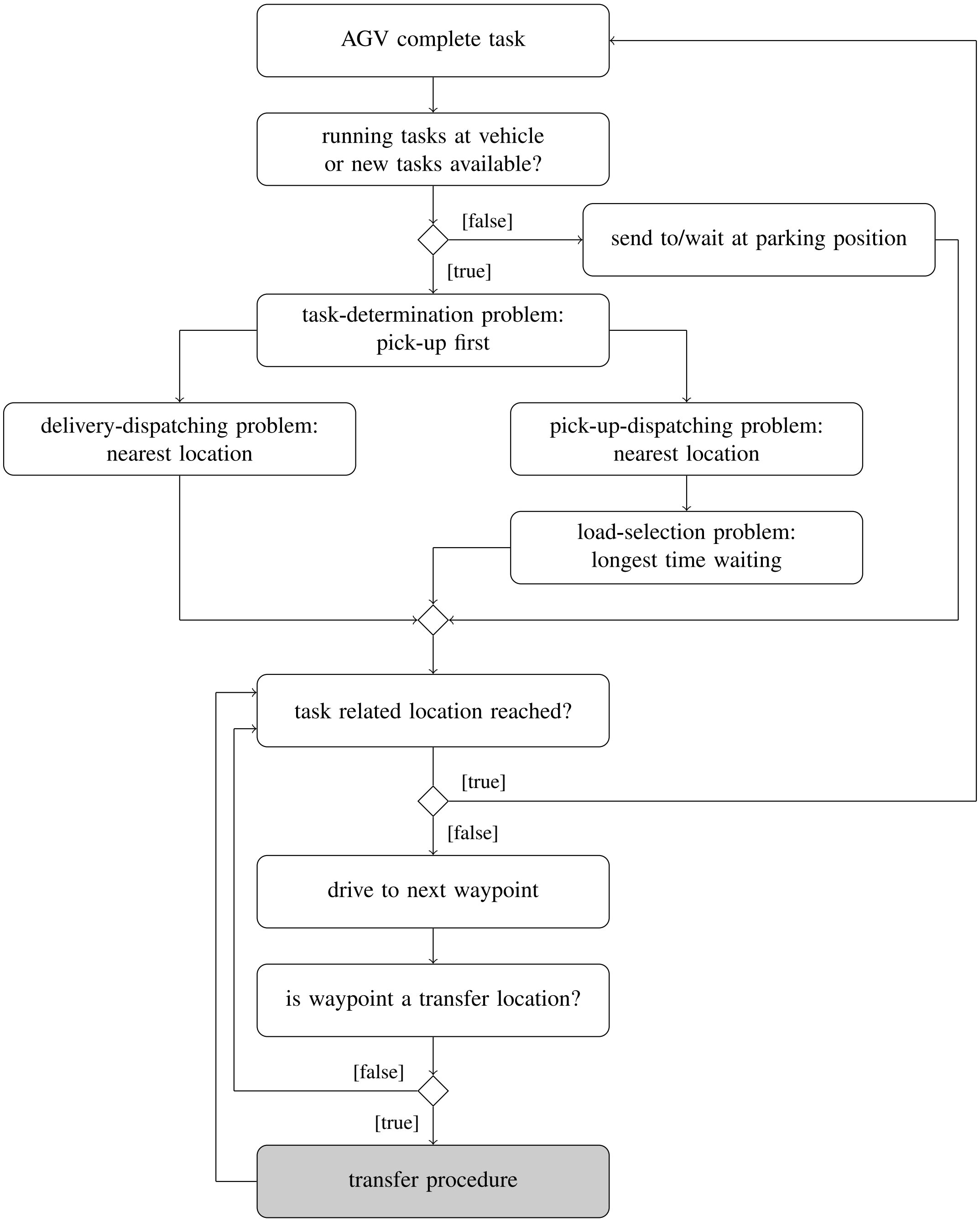

Figure 1: Dispatching algorithm with a transfer procedure to consider transport load transfers.

To update the AGV fleet's operational schedule, we assume that vehicles fulfill their current task (like a pick-up of a transport job) before reacting to new planned operations.

In the following, the dispatching algorithm will be evaluated in two stages. In Section 4, test instances are used to introduce and characterize the algorithm and elaborate which system configurations are suitable. Section 5 extends the analysis by taking dynamic system behavior into account and shows how our dispatching algorithm perform compared to dispatching without transfers (by the pick-up first-shortest distance strategy). Therefore the results from a descrete event simulation study are presented (see Section 5).

Algorithm 1 Transfer procedure.

```
function TRANSFER PROCEDURE( initial solution $s$, set of vehicles $K$, vehicle at transfer location $kt$, accept threshold $thres$ )
    $TL$: transport loads on $kt$
    $c_{best} = cost(s)$
    $s' = s$
    for $tl \in TL$ do
        for $k \in K$ do
            if $k \neq kt$ then
                remove $tl$ from $s'$
                insert $tl$ in $s'$ for transport by vehicle $k$
                if $cost(s') < (c_{best} - thres)$ then
                    $c_{best} = cost(s')$
                    $s = s'$
                    brake
                else
                    $s' = s$
    return $s$
```

4 DISPATCHING ALGORITHM EVALUATION BY TEST INSTANCES

We use test instances to get insights into the behavior of the dispatching algorithm and to study the influence of essential system characteristics. A test instance represents a scenario with a fleet of vehicles that need to fulfill several transport tasks. The scenario is generated in a generic way to study the effects in general and not specifically for a particular scenario. Nevertheless, we consider typical system dimensions for AGV to conclude the benefits in the intralogistics domain.

Vehicles are defined by velocity, handling time, capacity and start-/end locations. Transport tasks are characterized by start and end location. Transfer locations can be used to buffer transport loads without capacity restrictions. To create a test instance, transport jobs, vehicles and transfer locations are defined by us. Locations' coordinates are set randomly (see Figure 2). The vehicles drive on the direct path (Euclidian distance) between these locations. Vehicles consider transfer locations if the detour extends the intended route by a maximum of 5 % to ensure that they are regularly passed. For simplicity, we assume no vehicle conflicts (e.g., deadlocks). The parameter *thres* (see algorithm 1) was determined experimentally and set to 60 s.

4.1 Introductory Example

Figure 2 and Table 1 show a solved test instance considering transfers. A fleet of 2 vehicles (k in K) needs to carry out 4 transport jobs (j in J) under consideration of 4 transfer locations (t in T). The vehicles have a capacity of 2 transport loads, a handling time of 10 s and a velocity of 1 m/s.

The vehicles pick-up (P) and drop-off (D) transport loads at the start (S) and end (E) locations of transport jobs as shown in Figure 2. Transfer location t_1 is used for transport load transfers. Vehicle k_0 deposits the transport load j_3 (D_{j3} *at* t_1) and proceeds to pick-up j_2 (P_{j2} *at* S_{j2}). The operation was beneficial because vehicle k_1 was already carrying transport load j_0 with a similar drop-off location (see E_{j3}, E_{j0}). When vehicle k_1 reaches the transfer location t_1, a new transfer evaluation was carried out. Here the algorithm decides for the vehicle to leave j_0 and j_3 (D_{j0}, D_{j3} *at* t_1) and to return to the vehicle end position (E_{k1}). This option provides cost savings because vehicle k_0 can visit t_1 with a short detour and both transport job end locations (see E_{j3}, E_{j0}) are close by to the vehicle end location (E_{k1}).

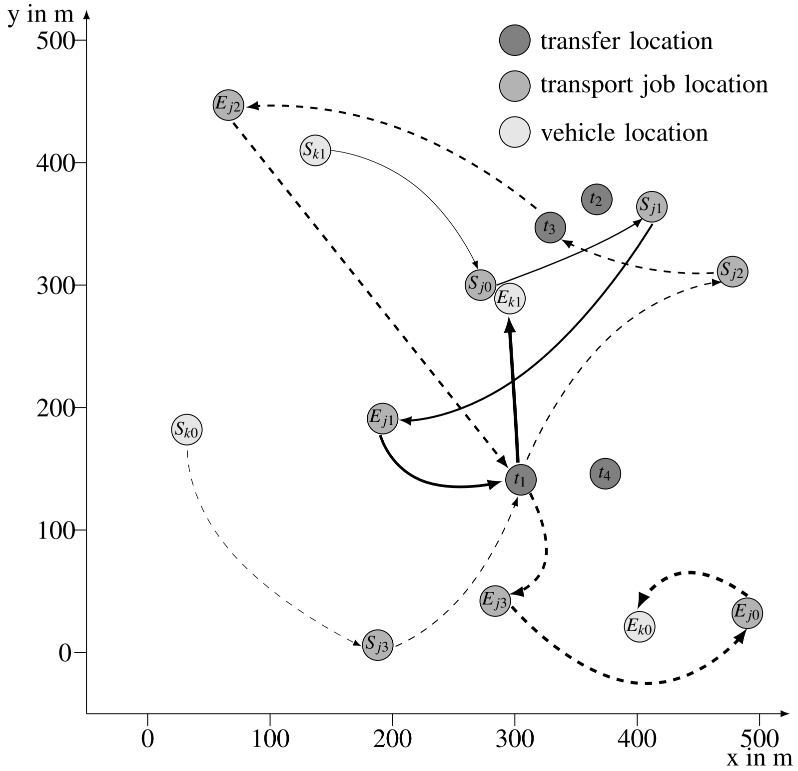

Figure 2: Solved test instance considering transfers (note: vehicles move on direct path between the points; (S) start location, (E) end location).

Seq.	k_0	k_1
1	D_{j3}	
2		D_{j0}
3		P_{j3}
4		D_{j3}
5	P_{j0}	
6	P_{j3}	

Table 1: Sequence at t_1; (P) pick-up, (D) drop-off.

If transfers are neglected, the vehicles would proceed in the following way: $k_0 : S; P_{j3}; P_{j2}; D_{j3}; D_{j2}; E$ and $k_1 : S; P_{j0}; P_{j1}; D_{j1}; D_{j0}; E$. Compared to this schedule, cost savings (operation time of vehicles for driving and handling) of 13.4 % could be achieved and the makespan was reduced by 4.1 %. It also shows the ability of our dispatching algorithm and its transfer calculation procedure to calculate beneficial transfer actions. Besides, it shows that transfers are planned based on the current system situation and that a rearrangement is also possible.

4.2 Influence by System Characteristics

We analyzed various system characteristics to examine their influence/effect on the concept of transfers based on our algorithm in AGV systems. First, handling times are subject of the analysis and are supposed to vary between 5 and 60 s. Table 2 shows corresponding results based on 3000 different scenarios (test instances). The table lists the amount (ratio) of scenarios in which at least one transfer was beneficial and accordingly the related system improvement.

Table 2: Handling time influence to the benefit of transfers (# of test instances = 3000).

Handling time	Scenarios transfers are beneficial	Average improvement
5 - 10 s	36.3 %	3.9 %
30 s	26.8 %	2.3 %
60 s	16.3 %	1.6 %

It becomes obvious that with increasing handling times, transfers become less attractive and the resulting benefit decreases. In detail, compared to short handling times with 5 to 10 s, here 36.3 % of the test instances operate transfers and the average improvement was 3.9 %, the effect is strongly decreased by higher handling times. However, even with a handling time of 60 s transfers lead to improvements. For 16.3 % of the test instances, an average improvement in cost for driving and handling of 1.6 % was observed.

A summary of effects by transport job, transfer location and vehicle parameters is given in Figure 3. The results are based on a full factorial experiment testing each parameter combination 10 times (around 29000 instances). Each of the test instances was solved in less than 1 s. Thus we assume that the algorithm works fast enough to control a vehicle system of similar size in real-time. Over all 20.2 % of the test instances contain at least one transfer operation whereat system performance improvements ranging from 2.9 % on average to 32.7 % on maximum. The single diagrams demonstrate that the parameters influence the probability that transfers will improve to varying extents. Furthermore, we revealed that the advantageous combination of high effect parameter values allows improving a higher share of test instances. As an example, for scenarios with an increased number of transport jobs (12), transfer locations (6) and vehicles (6), we found 50 % of the test instances improved by transfers.

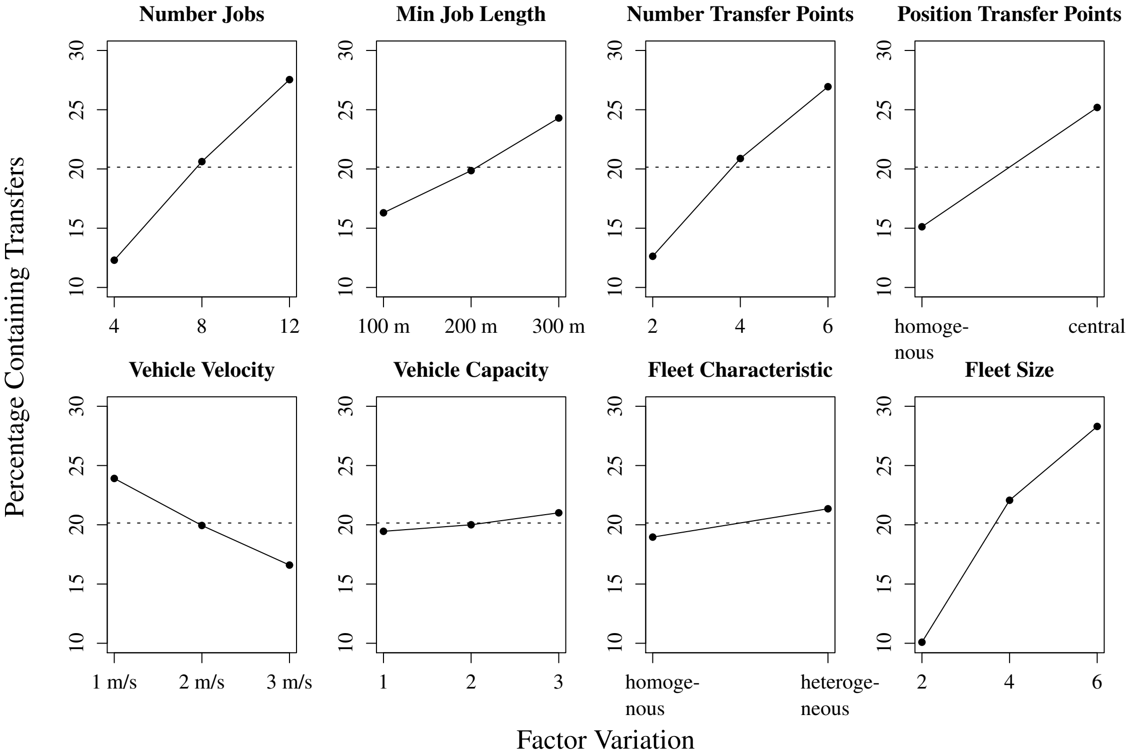

Figure 3: Effects of system parameters on the percentage of test instances containing at least one transfer operation. The average for all test instances is illustrated by a dotted line at 20.2 %.

Concerning the characteristic of transport jobs, we varied the parameters 'Number Jobs' and 'Min Job Length'. More jobs, raise the number of possible combinations to build schedules. This increases the chance that a beneficial transfer operation occurs. With 4 transport jobs for 12.3 % and 12 transport jobs for 27.5 % of the instances, transfers are beneficial - similar for job lengths as long transport distances increase detours for the vehicles to reach the following locations in their schedule. These detours can be lowered by transferring to another vehicle by synergy effects (e.g., same destination of jobs). Instances containing transfers ranging from 16.3 % for 100 m to 24.3 % for 300 m minimum transport distance.

The parameters 'Number Transfer Points' and 'Position Transfer Points' also have significant influence. If transfer locations are in the right place, they can be integrated with low detours to the schedules of the vehicles. This highly raises the chance that the vehicles can use them for transport load exchange to reduce costs. For central positioning, we use a central area that is one-fourth the size of the total area to locate transfer locations randomly. We see that more transfer locations and a central placement increase the share of instances in which transport load transfers occur from 12.6 % for 2 transfer locations to 26.9 % for 6 transfer locations, as well as 15.1 % for a homogenous and 25.2 % for a central placement.

Further: If 'Vehicle Velocity' increases, transfers become less attractive as costs for handling times become more relevant. The plot shows that the share of instances containing transfers reduces from 23.9 % for 1 m/s to 16.6 % for 3 m/s.

We saw no relevant influence for 'Fleet Characteristic' and 'Vehicle Capacity'. With the parameter 'Fleet Characteristic', we tested if there is an effect between scenarios where all vehicles have the same characteristics (homogenous) or different characteristics (heterogeneous) in velocity, handling time and capacity. Concerning vehicle capacity in about 20 % of the scenarios load transfers occur, even if the vehicles' capacity is set to 1. Synergy effects can also be achieved without running transport jobs on the receiving vehicle. Often vehicles drive empty for a considerable distance to reach a pick-up location for a transport job or the designated vehicle end location. On their way, they could be used to transport items. The effect concerning vehicle end positions also explains why, as the number of vehicles increases, the number of instances that contain at least one transfer operation rises. The share of instances containing transfers was for 2 vehicles 10.1 % and for 6 vehicles 28.3 %.

5 CASE STUDY

We verify by a material flow simulation study the advantageousness of transport load transfers and the approach's applicability to control AGV systems. The experiments are related to an example layout shown in Figure 4. The layout is characterized by a unidirectional path topology with 36 positions to start/end transports and 9 transfer locations. To avoid blocking, each transfer location holds an individual position for each vehicle. Transfer locations can be used to buffer transport loads without capacity restrictions.

The following experiments consider a fleet of 4 vehicles with a velocity of 0.5 m/s, a capacity of 2 transport loads and a handling time of 5 s. Transport jobs are randomly generated in advance with a minimum distance of 100 m. These parameters are assumed to be reasonable for intralogistics applications from our experience. Following the results from Section 4 the higher the number of transport jobs, the greater the chance that load transfers occur. We varied the number of transport jobs for the case study by assuming different utilization levels applying different interim arrival times of new transport jobs. Based on preliminary tests, we have determined that executing 25 repetitions with different seeds per factor combination is sufficient to achieve reliable results. The parameter for evaluating possible transfers (*thres*, see algorithm 1) was determined experimentally and set to 120 s.

For evaluation, we will focus on the cost for transport execution like in Section 4 as a sensitive indicator for improvements. Costs are calculated based on the operating time the vehicles spend for driving and transport load handling. To provide more general insights on the effect on system performance, we will evaluate vehicle utilization based on vehicle status information. We consider a vehicle as idle, when it is waiting at the parking position for new transport orders. This allows taking into account further impacts such as waiting times due to vehicle conflicts (e.g., at transfer locations). By evaluating the delivery time of transport loads, we want to make sure that despite the waiting of transport loads at the transfer point, the adherence to delivery dates is not affected overly.

Table 3 sums up the results of the simulation study. It shows that transfer operations are frequently executed to improve (see Δ handling). All in all, the amount of handling operations is increased by 9 % due to transports that are split into two or even more sub-transports. On the other hand, the execution of transport load transfers leads to an overall improvement of costs for driving and handling of 1.2 %. The reduction in vehicle utilization is 0.6 %. The improvement is accompanied by an average delivery

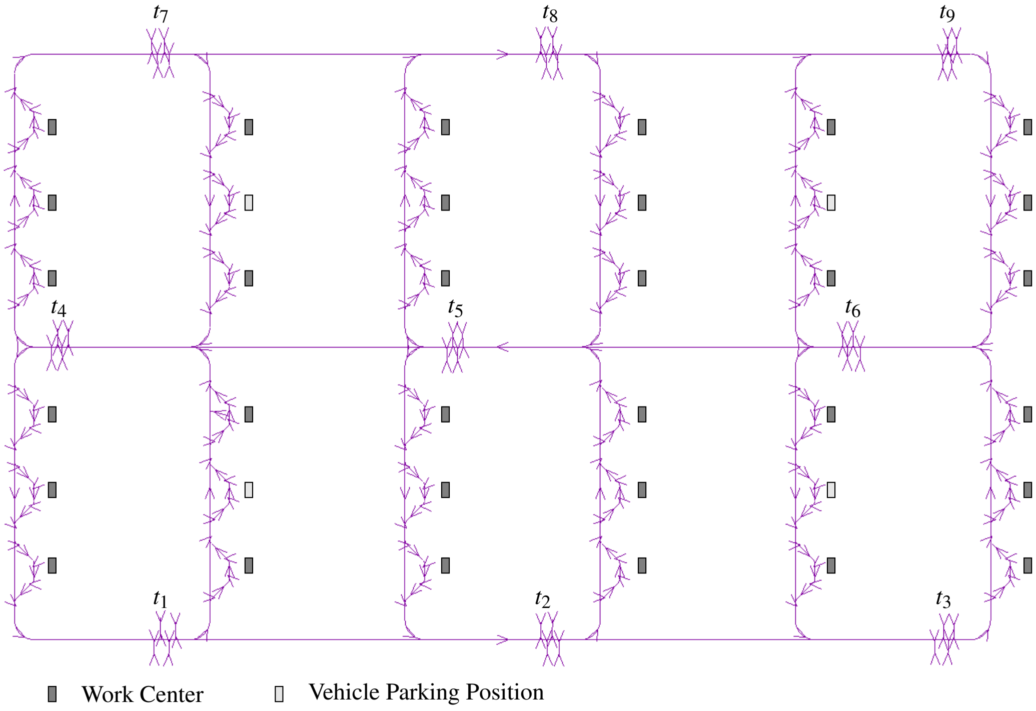

Figure 4: Layout of the simulation model with a dimension of 50 m in width and 30 m in height.

time increase of 2.7 % since transport loads are buffered at the transfer locations. These effects are highly dependent on the throughput of the system.

When the interim arrival time is 200 s, load transfers lead to an average improvement in costs of 1.6 % and vehicle utilization of 1.0 %. On the downside, the delivery time raises on average by 3.2 %. The transfer operations are rising with increasing throughput since there are more options to build schedules under transfer operations. For an interim arrival time of 120 s, the number increased by 12.4 % on average (delivery time average increase was 5.2 %). A cost reduction was measured on average by 2 %.

In highly utilized scenarios, we observed a reduced amount of transfer operations. Since the capacity of the vehicles is more utilized, there are fewer options to transfer items. In detail, for an interim arrival rate of 65 s on average 5.2 % more handling operations are executed, accompanied by a cost improvement of 0.4 %. In contrast to the other experiments, a significant reduction in delivery times results from applying transfers on average by 3.8 %.

Based on the results of Section 4 we started evaluating further configurations. We have also found for simulation that an increase in vehicle velocity or handling time leads to a drastic reduction of transfer operations. With the configuration of vehicle velocity 1 m/s, handling time 30 s and interim arrival

Table 3: The effect of transport load transfers in relation to system throughput (# of simulation runs = 250).

Interim arrival time of transports [in s]	65	70	80	90	100	120	140	160	180	200	Average
Delivery time [in s]	1070	804	632	529	482	442	435	431	430	430	-
Utilization [in %]	99.5	99.5	99.5	99.3	99.0	97.6	95.1	91.2	86.2	80.8	-
Δ # handlings [in %]	+5.2	+5.8	+7.7	+10.8	+12.2	+12.4	+11.6	+9.7	+8.1	+7.3	+9.0
Δ cost [in %]	-0.4	-0.1	-0.2	-0.6	-1.2	-2.0	-2.2	-2.0	-2.0	-1.6	-1.2
Δ utilization [in %]	0.0	0.0	0.0	-0.1	-0.2	-0.7	-1.1	-1.2	-1.4	-1.0	-0.6
Δ delivery time [in %]	-3.8	-0.4	+1.6	+3.1	+4.3	+5.2	+5.7	+4.5	+3.8	+3.2	+2.7

time 200 s we found no transfer operations. However, the algorithm works here equivalent to common dispatching neglecting transfers by the pick-up first-shortest distance strategy and no negative effects on system performance are caused. In contrast, an increase in the minimum transport distance leads to a higher relevance of transfers. So far, the highest cost improvement was measured for vehicle velocity 0.4 m/s and a minimum transport distance of 120 m. With an interim arrival time of 170 s, the costs for driving and handling are reduced on average by 4.3 % and at maximum by 5.3 %. The utilization of the vehicles was reduced on average by 3 % and at maximum by 4 %.

6 CONCLUSION

This paper presents a dispatching algorithm to control AGV systems allowing transport load transfers. Transfer operations are planned ad-hoc considering the current system state: when a vehicle passes a predefined transfer location, a transfer procedure evaluates if dropping the load to be then collected by another vehicle is beneficial in terms of reduced transportation costs (e.g., measured in time for driving and handling). The approach is embedded in a standard multiple-load dispatching strategy which also serves as a reference for the evaluation.

The algorithm was evaluated using static test instances and a material flow simulation study to consider systems' dynamics and stochastics. The test instances represent scenarios with different characteristics, e.g., in varying vehicle velocity or a minimum distance of transport jobs and led to an average improvement in cost of 2.9 %. Whereat for single scenarios, the application of transport load transfers resulted in system performance improvements of more than 30 %. The results demonstrate that improvements by the algorithm are sensitive to parameters like transport distance or handling time. Besides that, the experiments revealed that the calculation times are suitable for real-time control as computation times of less than 1 s in maximum were observed.

Applying a dynamic simulation study, we found that the effect of transport load transfers highly depends on the system throughput. For low throughput scenarios, on average benefits in cost of 2.2 % are observed and therefore positive impacts on vehicle utilization (1.4 %) are shown. So far, the greatest cost improvement for driving and handling was measured with 5.3 % and on vehicle utilization by 4 %. As mentioned before, this comes along with increased delivery times since the transport loads are buffered at the transfer locations and vehicles potentially need to drive detours. For high throughput scenarios, positive effects on the delivery time are reported with an average improvement of 3.8 %.

The application for larger fleet sizes is the subject of further research. The analysis of static test instances demonstrates that the approach benefits systems with a higher number of transport jobs and vehicles. Also, adaptions of the algorithm allowing the consideration of open transport tasks that are scheduled to be done subsequently by the vehicles and the positioning of transfer locations provide the potential for improvements. Finally, it needs to be evaluated which results can be achieved with alternative dispatching strategies for AGV (e.g., preference of drop-off tasks) under consideration of transfers.

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