

Battery Charging Strategies for AGV Systems

Energieladestrategien für FTS

Dominik Colling
Julien Oehler
Kai Furmans

*Institute for Material Handling and Logistics (IFL)
Karlsruhe Institute of Technology*

Automated guided vehicle systems are used for internal material transport. Due to technical advances, modern vehicles are no longer fixed to a track. This gives them more flexibility but makes it more difficult to charge their batteries while driving. They therefore have to visit charging stations to be charged. They are not available for material transport during the charging process. If too many vehicles have to charge at the same time, the system can no longer guarantee the planned throughput. In this work, battery charging strategies were developed to prevent too many vehicles from charging at the same time. The strategies were then tested in a simulation study and their effectiveness could be demonstrated. There were always enough vehicles available so that no orders were processed late. If the strategies were not used, delays occurred.

[Keywords: Automated guided vehicles, AGV, battery charging management, battery charging strategies, energy management]

Fahrerlose Transportsysteme werden für den innerbetrieblichen Materialtransport genutzt. Aufgrund technischer Fortschritte sind moderne Fahrzeug nicht mehr spurgebunden. Das verleiht ihnen mehr Flexibilität, erschwert aber das Laden ihrer Batterien während der Fahrt. Sie müssen daher zu Ladestationen fahren. Während des Ladeprozesses stehen sie nicht für den Materialtransport zur Verfügung. Müssen zu viele Fahrzeuge gleichzeitig geladen werden, kann das System nicht mehr den geplanten Durchsatz leisten. In dieser Arbeit wurden Batterieladestrategien entwickelt, die es verhindern, dass zu viele Fahrzeuge gleichzeitig laden. Die Strategien wurden innerhalb einer Simulationsstudie getestet und ihre Wirksamkeit konnte gezeigt werden. Es waren immer ausreichend Fahrzeug verfügbar, sodass keine Aufträge verspätet bearbeitet wurden. Wurde auf die Strategien verzichtet, kam es zu Verspätungen.

[Schlüsselwörter: Fahrerlose Transportsysteme, FTS, Batterieladeverwaltung, Batterieladestrategien, Energieverwaltung]

1 INTRODUCTION

Due to advances in navigation and safety technologies the flexibility of automated guided vehicles (AGV) increases. By using laser scanner-based navigation hardly any infrastructure is required for operation. For example, the expensive and difficult to adapt installation of guide wires for inductive track guidance is no longer necessary.



Figure 1. KARIS PRO, an exemplary AGV system [Col16]

However, the absence of infrastructure also leads to new challenges. The vehicles can no longer be recharged while driving but have to drive to dedicated charging stations where they have to wait until the charging process has been completed. During such a charging process, the vehicles are not available to process orders. If too many vehicles have to charge at the same time, the system can no longer guarantee the required throughput.

This effect has already been proven in scientific work [McH95] but has widely been neglected in further research [Vis06].

This work aims to develop two simple strategies for the battery charging management and to test their quality by means of a simulation.

This work is organized as follows: In section 2 the components of an AGV system (AGVS) are discussed and the task of the battery charging management is categorized into the overall tasks of an AGVS. Section 3 examines the existing literature and strategies for the battery charging management are presented. In section 4 a simulation study to examine these strategies is carried out, and the results are evaluated. Finally, the conclusion is described in section 5.

2 AGV SYSTEMS

According to VDI guideline 2510 [VDI05a] an AGVS (see figure 1) consists of:

- one or several AGVs (see section 2.1)
- a guidance control system (see section 2.2)
- devices for position determination and localisation
- data transmission equipment
- infrastructure and peripherals

AGVS are usually used for in-house material transports, e.g. at warehouses, production facilities and airports.

2.1 AGVs

In VDI guideline 2510 the primary parts of an AGV are described in detail.

In the following we will consider vehicles which can navigate freely (i.e. they are not fixed to a track, see an example in figure 2). This can be achieved for example by using a 2D-laser scanner for localization and mapping as used for the vehicles of the KARIS PRO system [Col16].



Figure 2. KARIS PRO vehicle

According to [McH95] the energy supply of electric AGVs can be maintained either by changing the batteries (manually or automatically) or by charging the batteries at charging stations or while driving. We will assume that the vehicles have built-in batteries. We further assume that there is no possibility to charge on the route and that the batteries are permanently installed. Therefore, the AGVs must regularly visit a charging station. Since the assumed charging time is relatively long compared to the transport times, charging will only take place between the processing of orders.

2.2 AGVS GUIDANCE CONTROL SYSTEMS

AGVS usually have a central guidance control system. The requirements for such systems are described in VDI guideline 4451 part 7 [VDI05b].

According to the guideline an AGVS guidance control system is defined as a computer program for coordinating several AGVs and integrating the AGVs into in-house processes.

The main component is the transport order processing which provides three functions: The transport order management, vehicle dispatching and travel order processing. Transport order management checks transport orders with regards to their feasibility and sorts them according to their priority. The vehicle dispatching function assigns the orders to the vehicles following predefined criteria. It is also responsible for handling empty vehicles by sending them to a waiting position or to a charging station and is thereby responsible for the battery charging management. The travel order processing function derives individual tasks from orders and is forwarding them to the vehicles. It controls the order execution and provides a travel guidance system to avoid collisions.

3 BATTERY CHARGING STRATEGIES

The absence of a charging level control system for a fleet of battery-operated vehicles can lead to many batteries being discharged at the same time and consequently to many simultaneous visits of the charging station. This may result in an insufficient number of vehicles available to process transport orders.

This has a great influence on the performance of an AGVS [McH95, Ebb01]. Nevertheless, this issue has so far been widely neglected in research [Vis06, LeA06].

The existing approaches for the battery charging management are described in section 3.1. In section 3.2 the strategies to address the issue are described.

3.1 BATTERY CHARGING STRATEGIES IN LITERATURE

3.1.1 VDI GUIDELINE 4451 PART 7

According to VDI guideline 4451 part 7 [VDI05b] the battery charging management is part of the vehicle dispatching module of the transport order processing (see section 2.2). This process allocation implicitly assumes that vehicles charge between two jobs. The guideline states that the charging strategy depends on the used battery type and the charging method.

It names two strategies:

- Battery charging at the end of the shift.
- Constantly monitoring the battery and creating a transport order towards a battery charging station when the battery discharge degree is below a certain limit.

These two strategies only offer a mechanism to avoid vehicles from stopping and blocking the routes due to discharged batteries but don't offer a control mechanism that guarantees a sufficient availability of vehicles for processing the transport orders.

3.1.2 MCHANEY, 1995

McHaney [McH95] doesn't offer strategies either but names three situations where a battery charging management isn't necessary:

- The vehicles operate only in short shifts with long breaks in-between so that the batteries won't get completely discharged.
- The system is underutilized in a way that vehicles have always the possibility to charge their batteries and no conflicts with urgent orders occur.
- The vehicle batteries can be charged sufficiently while driving.

3.1.3 EBBEN, 2001

Ebben examines the logistical control structure for transport networks and uses an AGVS for Amsterdam's Schiphol airport for his research [Ebb01]. He names three strategies for identifying good moments for charging:

- A vehicle can't process further orders due to the discharge of its battery.
- Before a known peak in orders.
- During waiting times (no orders in the system, capacity limited route is blocked by other vehicle).

The first and third strategy are vehicle centric approaches to maximize the availability of a vehicle and thereby only indirectly maximize the throughput of the AGVS. The second strategy addresses systems with variable throughput but doesn't offer a concrete approach how to address the issue.

3.1.4 PAGANI, COLLING AND FURMANS, 2018

Pagani, Colling and Furmans [Pag18] propose a neural network-based algorithm to simultaneously allocate orders to vehicles and decide which vehicles should visit a charging station.

As a neural network decides, the decisions can't be comprehended by the user. As the decision process for job allocation is integrated with the battery charging management, it's also not possible to determine own job allocation priorities.

3.2 HEURISTIC APPROACH

In this section we will present three strategies for controlling the battery charging levels of AGVs. For describing the strategies, we use the following parameters:

- n denotes the number of vehicles in the AGVS.
- m denotes the number of available, i.e. not charging, vehicles in the AGVS.
- b_s denotes the lower safety battery level in percent. If a vehicle battery level falls below this level, it visits a charging station after finishing its current order. b_s has to be set high enough so that the vehicles are always able to process an order and can subsequently reach a charging station.
- b_u denotes the usable battery capacity in percent. It is the difference between a full battery, which corresponds to 100% charging level, and b_s . If we assume b_s to be 20%, then b_u is 80%.
- If a vehicle battery level falls below the battery limit b_l the vehicle visits a charging station as soon as it is idle, i.e. if it is waiting or has just finished a transport order. b_l is higher than b_s and is used for sending vehicles to a charging station before it becomes necessary to avoid starving.

3.2.1 LOWER BATTERY LIMIT

The lower battery limit strategy is the simplest approach and already mentioned in (see subsections 3.1.1 and 3.1.3). b_l is equivalent to b_s . The vehicle batteries will be constantly monitored. As soon as the vehicle battery falls below the safety battery level b_s and the vehicle is idle, it gets sent to a charging station.

$$b_l = b_s$$

With this strategy, there is no AGV system wide control of the vehicles' availabilities, but the vehicles are prevented from starving on the route and thereby blocking other vehicles.

3.2.2 STEPWISE REDUCED LOWER BATTERY LIMIT

The idea behind the stepwise reduced lower battery limit strategy is to have a uniform distribution of battery levels over the whole fleet. This is why the lower battery limit is adapted according to available vehicles in the fleet.

The proposed solution for the battery limit is:

$$b_l = (m - 1) * \frac{b_u}{n} + b_s$$

If there are for example four of four vehicles available and the lower safety limit b_s is 20%, then the first vehicle will be sent to a charging station if its battery level falls below 80%. A second vehicle will be sent to a charging station, if its battery level is below 60%. The third if its battery level is below 40% and the fourth if its level is below 20%.

3.2.3 EVENLY SHIFTED BATTERY CHARGING AND DISCHARGING CYCLES

By using the evenly shifted battery charging and discharging cycles strategy (cycle strategy), we assume that all vehicle batteries continuously pass through a cycle (see figure 3). A fully loaded battery discharges until it falls below the safety battery level b_s . Then the battery is fully charged again. Afterwards the cycle starts all over again.

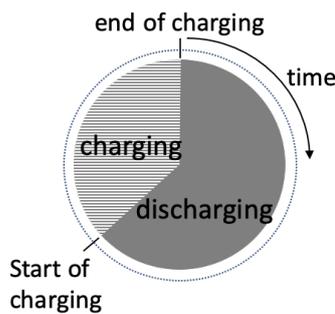


Figure 3. Cycle of charging and discharging

We can estimate the discharging as well as the charging time. The idea is to uniformly distribute the battery charging levels of the vehicles in the AGVS over this cycle so that the time interval between two vehicles going to a charging station is equal. Thereby the number of vehicles at a charging station is constant or rather only differing by one vehicle.

Therefore, we have to control the interval between the vehicle batteries and have to take action if necessary, to keep the distances.

As the charged energy per time is assumed to be constant and the discharged amount is defined by the distance travelled, we can only take corrective action by sending vehicles to a charging station earlier than it would be enforced by the safety battery limit (see figure 4).

Cycle Time

The cycle time needs to be estimated continuously since discharging times may vary depending on the number of orders being processed per time.

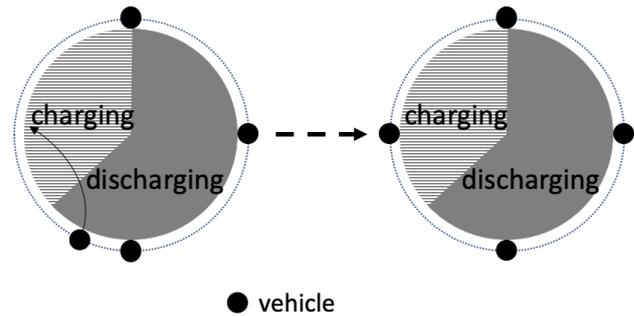


Figure 4. Sending a delayed vehicle to a charging station
 Calculating the initial cycle time

In the beginning a cycle time can be estimated by assuming the AGVS will work at full load. If the vehicle can be charged with a charging rate cr and has, under full load, a discharging rate dr , the cycle time can be estimated as follows:

$$cycletime^{initial} = \frac{b_u}{cr} + \frac{b_u}{dr_{initial}}$$

Updating the cycle time

Each time a vehicle starts its battery charging, its discharging time (or time since recharge t^{SR}) and its battery consumption per time of the last discharging phase (or battery consumption since recharge bc^{SR}) can be calculated. The discharging rate dr can therefore be updated as follows:

$$dr^{updated} = \frac{t^{SR}}{bc^{SR}}$$

Based on these values the discharging time, assuming b_u would have been used completely, can be derived:

$$cycletime^{updated} = \frac{b_u}{cr} + \frac{b_u}{dr^{updated}}$$

After the calculation this value is stored and a mean cycle time ($cycletime^{mean}$) which will be used for further calculations for all vehicles is calculated by using the moving average method.

Distance calculation

The moment when a vehicle finishes its charging is the reference point. It is defined as its starting time S . The starting times of all vehicles will be stored and define the position of the vehicle within the sequence by sorting them chronologically. If two vehicles pass the reference point at the exact same time, the vehicle IDs are decisive to determine the order.

Decision

Each time a vehicle finishes an order, its distance in the cycle to all vehicles which have finished their charging later than the vehicle will be calculated. The distance of the vehicle v which has finished an order to vehicle i which has passed the reference point later than v is defined by

$$d_{vi} = S_i - S_v$$

The target time interval between two vehicles v and w passing the cycle directly after each other is:

$$d_{vw}^{target} = \frac{cycletime^{mean}}{n}$$

Therefore, the target interval to the vehicle y after the next vehicle w is

$$d_{vy}^{target} = 2 * \frac{cycletime^{mean}}{n}$$

and so on.

Vehicle v will take its decision based on the maximum calculated delay. The maximum delay is defined by

$$delay_v^{max} = \max_i(d_{vi} - d_{vi}^{target}, 0)$$

If the delay is negative the vehicle can't take action, but if the delay is positive it could start its charging process earlier.

To compensate the delay, the time difference between vehicle v 's next starting time S_v^{next} and its last starting time S_v^{last} should be:

$$S_v^{next} - S_v^{last} = cycletime^{mean} - delay_v^{max}$$

We can derive S_v^{next} :

$$S_v^{next} = S_v^{last} + cycletime^{mean} - delay_v^{max}$$

Then the estimated starting time S_v^{est} of the vehicle v which it would reach if it would start charging immediately can be calculated by adding the current time and the charging time. The required charging time can be calculated by dividing the difference of the full battery level b_f and the current battery level $b_v^{current}$ by the charging rate cr :

$$S_v^{est} = currentTime + \frac{b^{full} - b_v^{current}}{cr}$$

If S_v^{est} is greater or equal to the calculated S_v^{next} the vehicle will visit a charging station and start the charging process to compensate its delay.

Example

Assuming we have three fully loaded vehicles. The vehicles charge with a rate of 1% per minute and discharge with a rate of 0,5% in continuous operation. We further assume b_s to be 40%. Then the cycle time would be 180 minutes since the vehicles will discharge its usable battery capacity within 120 minutes and will recharge within 60 minutes. Having a cycle time of 180 minutes and four vehicles, the aimed distance between the vehicles is 45 minutes. The delay of vehicle 1 to the other vehicles is, since all start at the same time, 45 minutes, 90 minutes and 135 minutes. So, the maximum delay is 135 minutes. Assuming S_1^{last} is 0, $cycletime^{mean}$ is 180 minutes and $delay_1^{max}$ is 135 minutes, you can calculate S_1^{next} , and get 45 minutes as result.

While discharging, vehicle 1 will continuously check its battery level. As soon as its forecasted end of its next charging is later than the 45th minute, vehicle 1 will visit a charging station.

4 SIMULATION STUDY

To determine the performance of the strategies a simulation study was carried out. In section 4.1 the (fictional) production environment, in which the vehicles are used, is presented. In section 4.2 the modelling of the environment in an event-based discrete simulation is described. In section 4.3 the results of the simulation study is summarized and discussed in section 4.4.

4.1 ENVIRONMENT

The production environment, in which the vehicles are tested, is derived from a real-world car manufacturing facility. The environment contains twelve transfer stations in a supermarket, twelve transfer stations next to an assembly line and six charging stations in the center (see figure 5).

We simulate an eight-hour work day which includes 16 work cycles of 30 minutes. In each work cycle twelve full load transports from the supermarket to the stations of the assembly line as well as twelve empty load transports from the assembly line to the stations of the supermarket have to be conducted. There's always a 1:1 relationship between the stations of the assembly line and the stations of the supermarket. Each transport has a distance of 70 m. The orders for the full load transports have to be prepared by four pickers. Each picker serves three stations of the system. The orders starting from the supermarket will start about 5 min, 10 min and 15 min after the start of a work cycle. The above-mentioned starting points are shifted up to 90 seconds due to the picker's individual service times. The shift is determined before the simulation run by a random number generator. The full load transports have to be finished by the end of the work cycle. The empty load transports start simultaneously with the work cycle (when

the assembly line worker change a full load cart with an empty load card). The empty load transports have to be finished by the end of the work cycle.

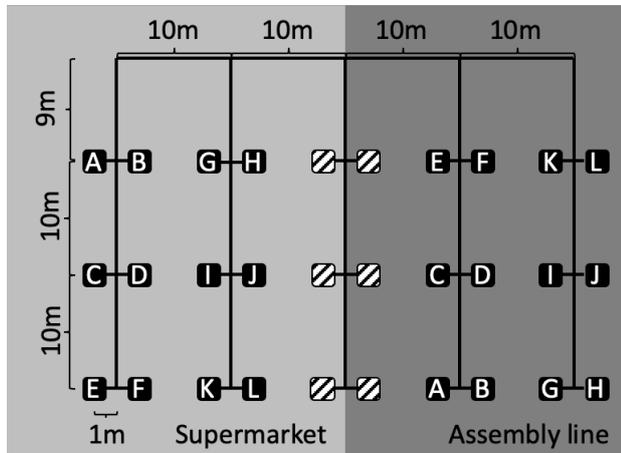


Figure 5. Layout of the environment

The AGVS contains six vehicles. In the beginning all vehicle batteries are fully charged. The safety battery level b_s is set to 30%. Each vehicle has one of the charging stations as a home base which it will visit if it needs to charge.

4.2 MODELLING

For modelling the environment, the MASON multi-agent simulation toolkit [Luk05] is used. Before each simulation run, the orders are created according to the description in section 4.1. The start times of the full load transports are generated with the Mersenne Twister random number generator [Mat98].

Table 1: list of parameters of the AGVs used for the case study

Parameter	Value
Vehicle speed with load	$0,5 \frac{m}{s}$
Vehicle speed without load	$0,7 \frac{m}{s}$
Time for positioning at stations	30 s
Time for transferring load	15 s
Energy consumption	$0,0015 \frac{\%}{m}$
Charging rate	$0,0333 \frac{\%}{s}$

The AGVS only knows the transport orders after their start time. The AGVS bases its decisions only on the current orders. No forecast is made. The most urgent order will be allocated first. This becomes relevant if there are delayed orders which couldn't be completed within one work cycle. If two orders are equally urgent, the first generated

order is allocated. If the orders are created at the same time, the order with the lower ID is selected.

If there is more than one idle vehicle available for an order, the closest vehicle to the starting point of the order is chosen.

The vehicles have a speed of $0,5 \text{ m/s}$ when loaded and $0,7 \text{ m/s}$ when unloaded. They need 30 seconds for positioning at transfer and charging stations and need 15 second for transferring load at transfer stations. The energy consumption is $0,0015 \%/m$ regardless of whether they are loaded or unloaded. The energy consumption for positioning and for transferring is neglected. The batteries are charged with a rate of 1% each 30 seconds which corresponds to $0,0333 \%/s$.

A vehicle is considered available if it is waiting for an order or if it is processing an order. It counts as unavailable if it is on its way to a charging station or if it is charging.

We log the job data and the battery charging processes. From this, we can derive the following performance measures for the strategies within each simulation run:

- Number of delayed transports in each run. A transport is delayed if it finished after its work cycle.
- The sum of the waiting times of all orders. The waiting time is the difference between the order creation time and the start time of the transport.
- The minimum number of available, i.e. not charging, vehicles within a simulation run.
- The average number of available vehicles within a simulation run.
- The number of charging processes conducted by the vehicles.

Three simulation experiments, one for each strategy (see section 3.2), are carried out. Each experiment consists of several simulation runs. After each simulation run the means of the above performance measures are calculated. As long as the relative standard error of a mean is higher than 2%, a new simulation run is conducted, and the experiment is continued. The maximum number of runs for one experiment is 50.

4.3 RESULTS

The results of the simulation are summarized in table 2. The abbreviation for the lower battery limit strategy is LBL, the stepwise reduced lower battery limit is named SRLBL, the evenly shifted battery charging and discharging cycles strategy is named CYCLE.

Table 2: list of simulation results

	LBL	SRLBL	CYCLE
Simulation runs	21	50	20
Mean number of delayed transports	44,43	0,02	0
Mean sum of waiting times (in seconds)	180389,9	123757,6	108838,3
Mean minimum available vehicles	0	4	4,8
Mean average available vehicles	5,53	5,15	5,44
Mean number of charging processes	6	35,86	10,05

4.4 EVALUATION

The LBL strategy performs worst. However, since the vehicles process orders until their battery charge falls below the lower battery limit, more vehicles are available compared to the other strategies. Also, the number of charging processes is the lowest, with only six which is one per vehicle. Nevertheless, as all vehicles visit their charging station at the same time, no vehicles are left to process the orders. This results in a mean of 44,43 delayed orders. Also, the sum of waiting times amounts to 180389,9 seconds, which is the highest value compared to the other strategies. Figure 6 shows a typical distribution of available vehicles for this strategy. The data has been recorded at the first simulation run.

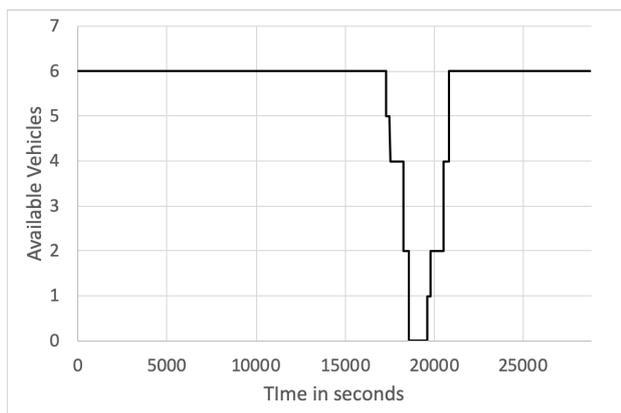


Figure 6. Available vehicles over time using the LBL strategy in an exemplary simulation run

The SRLBL strategy (see figure 7) avoids delayed transports with only one exception which result in a mean of 0,02 delayed transports. (This one exception leads to a high relative error so that 50 runs had to be carried out.) The sum of waiting times is lower compared to the LBL

strategy. On the other hand, the number of charging processes is the highest and the average number of available vehicles is the lowest.

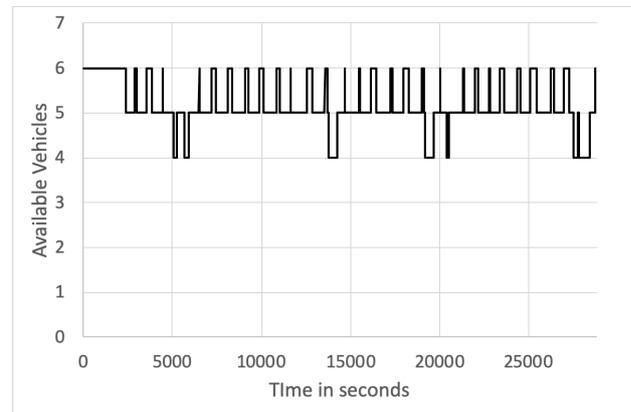


Figure 7. Available vehicles over time using the SRLBL strategy in an exemplary simulation run

The CYCLE strategy provides the best results (see figure 8). No transports were delayed, and the sum of waiting times is the lowest of all experiments. The number of charging processes is lower, and the average number of available vehicles is higher compared to the SRLBL strategy. The mean minimum number of available vehicles is 4,8 which is the highest number of all experiments.

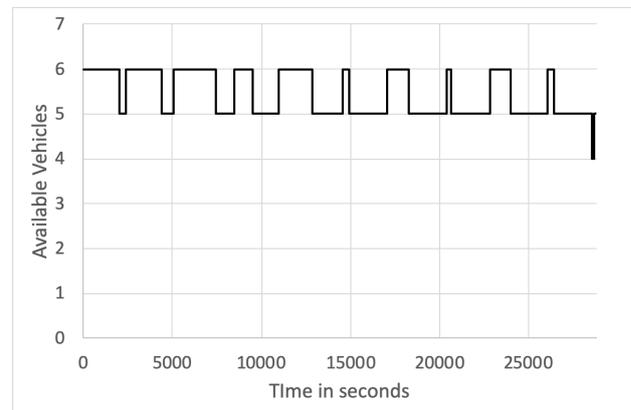


Figure 8. Available vehicles over time using the CYCLE strategy in an exemplary simulation run

5 CONCLUSION

The flexibility of AGVs increases. Thanks to new navigation technologies the vehicles are no longer fixed to a track but can drive freely. Fixed installed infrastructure is hardly necessary. However, this leads to the new challenge that the vehicle batteries can't be charged while driving. Battery powered vehicles need to visit charging stations regularly. If the charging and discharging process is not controlled, it is possible that too many vehicles need to charge at the same time and too few vehicles are available for processing orders.

Therefore, we introduced two new strategies for managing the battery charging process and tested them within an event-driven discrete simulation based on fictional, but real-world derived, scenario of a car manufacturing plant.

We showed that the absence of a strategy to coordinate the charging processes can lead to bad results as to many vehicles charge at the same time.

The simple strategy of adapting the lower battery limit based on the available vehicles already produces good results by avoiding delayed transport orders. However, this strategy leads to a higher number of charging processes and thereby reduces the average number of available vehicles.

The so-called cycle strategy produces the best results. This strategy tries to uniformly distribute the starting times of charging processes by sending vehicles earlier to charging stations than it would be necessary only considering their own battery level. This strategy avoids delayed transports, while at the same time, keeping the number of charging processes low.

In order to get a better understanding further simulation studies should be conducted considering different layouts, different vehicles and different order structures.

LITERATURE

- [Coll16] Colling D, Ibrahimasic S, Trenkle A, Furmans K, „Dezentrale Auftragsproduktion und -vergabe für FTF,“ *Logistics Journal: Proceedings*, Bd. Vol 2016, 2016.
- [Ebb01] Ebben, Mark. „Logistic control in automated transportation networks“. PhD diss., Twente University Enschede, 2001.
- [LeA06] Le-Anh, Tuan and De Koster, MBM, „A review of design and control of automated guided vehicle systems,“ *European Journal of Operational Research*, Bd. 171, Nr. 1, pp. 1-23, 2006.
- [Luk05] Luke, Sean, et al. "Mason: A multiagent simulation environment." *Simulation* 81.7 (2005): 517-527.
- [Mat98] Matsumoto, Makoto, and Takuji Nishimura. "Mersenne twister: a 623-dimensionally equidistributed uniform pseudo-random number generator." *ACM Transactions on Modeling and Computer Simulation (TOMACS)* 8.1 (1998): 3-30.
- [McH95] McHaney, Roger. "Modelling battery constraints in discrete event automated guided vehicle simulations." *International Journal of Production Research*, Bd. 33, Nr. 11: pp. 3023–40, 1995.
- [Pag18] Pagani, Paolo, Dominik Colling, and Kai Furmans. "A Neural Network-Based Algorithm with Genetic Training for a Combined Job and Energy Management for AGVs." *Logistics Journal: Proceedings*, 2018.10 (2018).
- [VDI05a] VDI 2510 (2005). Fahrerlose Transportsysteme (FTS). Verein Deutscher Ingenieure, Beuth-Verlag, Berlin.
- [VDI05b] VDI 4451 Blatt 7 (2005). Kompatibilität von Fahrerlosen Transportsystemen (FTS) -Leitsteuerung für FTS. Verein Deutscher Ingenieure, Beuth-Verlag, Berlin.
- [Vis06] Vis, Iris FA. "Survey of research in the design and control of automated guided vehicle systems." *European Journal of Operational Research* 170.3 (2006): 677-709.

M.Sc. Dominik Colling is working as a Research Assistant at the chair of Robotics and Interactive Systems, Institute for Material Handling and Logistics (IFL), Karlsruhe Institute of Technology (KIT).
E-Mail: colling@kit.edu

M.Sc. Julien Oehler completed his master thesis at the Institute for Material Handling and Logistics (IFL), Karlsruhe Institute of Technology (KIT).

Prof. Dr.-Ing. Kai Furmans is Head of the Institute for Material Handling and Logistics (IFL), Karlsruhe Institute of Technology (KIT).
E-Mail: kai.furmans@kit.edu

Address: Institute for Material Handling and Logistics (IFL), Karlsruhe Institute of Technology (KIT),
Gotthard-Franz-Str. 8, 76131 Karlsruhe, Germany