Enhancing Charging & Parking Processes of AGV Systems: Progressive Theoretical Considerations

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***Abstract*—This paper presents our work in progress for the development of an efficient charging & parking strategy. Our research aim is to develop a strategy that not only provides an efficient approach to charging Automated Guided Vehicle (AGV) batteries, but also reduces traffic density in a highly utilised large-scale AGV system. Alongside the current state-of-the-art solution, three new allocation methods are introduced: *Trivial+*, *Pearl Chain* and a method based on the *Generalised Assignment Problem (GAP)*. These four methods vary in their scope, in terms of number of vehicles considered, when calculating a decision for a specific vehicle. Furthermore, two types of availability rules for vehicles are introduced and evaluated. Their combination with the allocation methods lay the foundation for future research. All allocation methods and availability rules are explained in detail and this is followed by a summary of the expected outcomes.**

Keywords*—*AGVs; Automated Guided Vehicles; Battery Charging; Charging Strategy.

I. Introduction

Due to the increasing demand for individualised goods, and tighter production schedules, production and the related logistics have needed to become more and more flexible [1]. It follows that internal logistics have to adapt efficiently to the increasing dynamics and complexity of production processes. The visionary concept of Logistics 4.0 is proposed to offer a wide range of solutions for this [2] [3]. The use of AGVs, in particular, is gaining attention and is becoming the focal point of researchers across different industries [4]–[7].

AGVs are ready for use at any time of day, can be installed with relatively little effort and can move freely in their application environment, due to the lack of required physical guiding systems [8]. The increasing environmental flexibility means that vehicles can be used for a greater range of scenarios [5]. Taking into consideration the progressing flexibility and technological advances, Automated Guided Vehicles have the potential to play an important role in factory logistics [9]. Yet, it is proposed that the organisational complexity increases alongside with greater flexibility of application [10].

Besides the apparent problem of efficient task processing, other issues relevant to the resource efficient operation of the entire system require consideration. More specifically, this paper focuses on scheduling the charging and parking missions of the vehicles. Although this issue may seem to be trivial at first, it becomes increasingly complex for large-scaled and highly utilised systems. By choosing an optimal strategy, the vehicle fleet can be reduced to a minimum number of vehicles and thus fewer resources are necessary. The lower number of AGVs results in less traffic density, which in turn leads to fewer traffic jams and less blocked pathways [5]. As such, the charging strategy is proposed to be an important aspect and has the potential to improve the total performance of such a material flow system [11]. According to Ryck et al., this topic has not been explored in great detail so far [12].

Therefore, this paper considers and evaluates existing methods discussed in the relevant literature, and proposes concepts to address the issue of scheduling the charging and parking missions of the vehicles efficiently.

This paper is structured as follows: in Section II, we outline the environmental requirements that provide the theoretical framework of this study and Section III provides an overview of the relevant literature. The strategies that we have developed are introduced in Section IV . Finally, Section V and Section VI describe the experimental environment and the predicted outcomes of the projected simulation study. Its results are going to be presented in a subsequent publication.

II. Environmental Requirements

This section describes the parameters of our study, stipulated by the constraints of a research project undertaken by the BMW Group, to which we are contributing. For the automatisation of the the internal material flow, the BMW Group has developed the so-called Smart Transport Robot (STR) (see Figure 1), designed to substitute common tucker trains which currently play a central role in the automotive material handling processes. The industrial use-case of BMW Group specifies the following requirements:

1) Every vehicle can carry one load carrier at a time.
2) All transportation requests are issued randomly and therefore unknown prior to their receipt.
3) Vehicles without a task are required to either recharge or park.

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Fig. 1. BMW's STR in its natural habitat.

A. Optimisation Objective and Key Performance Indicators

The overall goal of an automotive transport vehicle system is to complete all tasks on time. This requirement is considered to be a hard constraint, which is non-negotiable to the detriment of any other Key Performance Indicators (KPIs). That is, in order to meet this requirement, other resource intensive variables are minimised to save resources. An important resource in an automotive production environment are the pathways. These are not only utilised by AGVs, but also by forklifts, tow trains, bicycles and pedestrians. In order to maximise their availability for purposes other than AGVs, the subsequent charging and parking strategy was developed.

Additional KPIs applied to evaluate the quality of loading strategies in terms of their flexibility, efficiency and scalability will be introduced below. In this context, flexibility is defined as the availability of as many vehicles as possible at any time, allowing for an immediate reaction to short notice events, such as highly-prioritised urgent tasks.

In order to assess the efficiency of a charging strategy, it is necessary to take into account the non-linear quality of the charging process. That is, the amount of time required to recharge a battery to a predetermined level depends on the initial State of Charge (SOC). This KPI can be evaluated by accessing the utilisation records of the charging stations.

As scalability is also an important variable of such a system, the required computational power needs to be considered. Consequently, a low computing effort is more likely to ensure that a later expansion of the fleet will not cause performance issues based on a lack of computational power.

Thus, a total of five KPIs are used to compare and evaluate the strategies presented in this paper.

B. Source of Energy

The Smart Transport Robot is supplied with energy from a lithium-ion battery module of BMW's electric vehicle i3. Side fact: the i3 is built of eight such modules. Each module contains twelve battery cells and has 48 V as well as a capacity of 120 Ah. The time required to fully charge one module by means of a common method like Constant Current Constant Voltage (CCCV) is 3.2 h. However, fast-charge methods are likely to reduce this duration substantially. The charging current for this method decreases from 38 and 36 A. CCCV and also other fast-charge methods have in common that they are are able to charge faster in a relatively small SOC than in a high one [13]–[15].

Lithium-ion batteries have a number of advantageous properties relevant to the practical application of AGVs. Especially the minimal negative memory effects of short charging periods over a few minutes should be emphasised. The memory effect refers to a loss of capacity which results from frequent partial discharges. This feature allows for efficient, short charging processes and continuous use over 24 hours [16]–[18]. More advantageous properties are, e. g. the long life-cycle, low levels of self-discharge, their price and their relatively small size and weight [16].

C. Task Allocation and Prioritisation

The tasks are allocated by a central operating optimisation algorithm in this experimental setting. The algorithm ensures that all tasks are performed on time, whilst minimising the driving effort of the vehicle fleet measured in meters. For this purpose, all driving efforts are transferred to a matrix that constitutes the associated GAP (for more details see Section IV-A4). The solution to the GAP, referred to as Vogel's Approximation Method for non-quadratic Matrices (VAM-nq), was developed by Selmair et al. [3], and is an extension of the original Vogel's Approximation Method (VAM) introduced by Reinfeld et al. [19]. Unlike exact methods like the *Hungarian Method*, proposed by Kuhn [20], and *Integer Linear Programming*, VAM-nq approximates a solution for the GAP. As a result, the quality of the solution is sufficient for most cases, but the algorithm computes solutions substantially faster than exact methods. For a detailed review, we refer the reader to Selmair et al. [3].

To ensure that all tasks are performed on time, the system uses a prioritisation method to schedule all tasks. This method ensures that the system uses the temporal flexibility of each task to minimise the driving effort of the AGVs. Extensive research has been conducted about this prioritisation method by Selmair et al. [21].

III. Relevant Literature

This section presents a description of the state-of-the-art planning strategies summarised in Table I and explains their findings, identifies possible weaknesses and defines potential for consolidation. Based on a review of the relevant literature, the following key components of an allocation method are identified:

- Timing of the charging process
- Choice of a charging station
- Duration of the charging process

Table I serves as the basis for a comparison and summary of planning strategies provided by studies on battery charging. On the basis of these studies, the findings are evaluated and examples of specific research are selected.

TABLE I. OVERVIEW OF ALLOCATION METHODS

	Timing	*Selection Criteria*	*Duration*
Ebben 2001 [22]	Intermediate / Charge Range	Heuristics	Duration of Battery Exchange
Kawakami & Takata 2012 [23]	Min. Deterioration	-	Duration of Battery Exchange
Zou et al. 2018 [24]	Intermediate / Below Threshold	-	Handling Time / Fully Loaded
Kabir & Suzuki 2018a [25]	Below Threshold	Heuristics	Duration of Battery Exchange
Kabir & Suzuki 2018b [11]	Below Threshold	Nearest Station	Fully Loaded / Above Threshold
Colling et al. 2019 [26]	Scheduled	Permanent Assignment	Fully Loaded
Selmair et al. 2019 [9]	Intermediate / Below Threshold	Minimal Costs	Fully Loaded / Displaced
Zhan et al. 2019 [27]	Below Threshold	Heuristics	Fully Loaded / Above Threshold

A. Timing of the Charging Process

The trigger that prompts the charging process is usually a predefined low battery charge level and it coincides with a point in time when a vehicle is not performing a task [9] [11] [22] [24] [25] [27]. In an effort to determine the optimal timing, Kawakami et al., for instance, focus on minimising battery deterioration [23]. However, as previously established, this aspect is deemed to be negligible when it comes to lithium-ion batteries.

Interestingly, Colling et al. distributed vehicles equally, by using charging cycles and thus focused the attention on the overall system [26]. However, the mentioned study is carried out on a system with six AGVs, it remains uncertain whether this method can be implemented for a larger system.

Charging idle vehicles, even if their battery charge levels are above the triggering SOC, also referred to as intermediate charging, is also suggested to be a feasible tool to enhance a charging strategy [9] [22] [24]. Possibilities for intermediate charging and the consideration of the SOC in comparison with other vehicles on the field or in charging stations could lead to an increase in flexibility, efficiency and scalability of the system. These considerations should also be taken into account and tested when developing the charging strategy.

B. Selecting a Charging Station

Heuristics can be particularly helpful in selecting a suitable charging station. Commonly, this involves selecting charging stations based on either their distance to an agent or that can be used with the least overall delay [11] [22] [27]. The total delay consists of the travel time to a station and the waiting time required by an AGV to use the charging station. In contrast, predetermining charging stations without monitoring the distance to and availability of charging stations, as implemented by Colling et al., does not appear to be feasible for a flexible and scalable system [26].

In fact, using heuristics can increase efficiency and flexibility. Furthermore, if the parameters allowed for the displacement of vehicles currently at a charging station by vehicles with a higher need for recharging, it is assumed that efficiency and flexibility can be increased.

C. Duration of the Charging Process

The duration of a charging process can either be defined as the time required to physically replace a battery [11] [22] [23] or to reach its planned SOC [24] [26]. Kabir et al. and Zhan et al. suggest that batteries should only be charged to a level of 90 % or 95 % to shorten the inefficient phase of a battery charge (see Section II-B) [25] [27]. All the mentioned studies have in common that only the condition of one AGV is considered in any decision. Selmair et al. provides a first method that take into account the condition of more than a single vehicle [9]. In their paper, two vehicles are compared with each other by using an objective function that includes the distance of a vehicle to an occupied station as well as the SOC of both. The following conclusions can be drawn from Selmair et al.: the possibility to interrupt a charging process due to tasks or displacements can increase flexibility. For this purpose, accurate parameters are necessary in order to achieve robust processes to attain a high level of flexibility.

IV. Developed Strategies

This section describes potential *strategies* for charging and parking vehicles, which maintain the availability of the vehicle fleet on the one hand, and minimise the distance travelled on the other. Every *strategy* can be divided into two aspects: the first is the *allocation method* itself (Subsection A) and the second pertains to the availability of a vehicle, referred to as *availability rule*, for tasks or charging and parking processes (Subsection B).

Table II illustrates the two aspects of the strategies in the form of a morphological box. Every combination of the left and the right column represents a strategy – with one exception: for the *Trivial* allocation method, which is derived from the current state of the art, only the first *availability rule* is applied.

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TABLE II. THE TWO COMPONENTS OF A CHARGING & PARKING STRATEGY

Allocation Method	*Availability Rule*
Trivial	Hard Constraint
Trivial+	Soft Constraint
Pearl Chain	
GAP	

A. Allocation Methods

The four allocation methods are presented in the order of their scope, in terms of numbers of vehicles considered by each method. Therefore, the first allocation method – namely *Trivial* – only takes into account the vehicle that requires either charging or parking. This allocation method is common in today's industrial transport vehicle applications (see Table I).

The *Trivial* allocation method is followed by three new allocation methods, which consider other factors than merely the vehicle that requires a charging or parking station. These are in namely *Trivial+*, *Parl Chain* and *GAP*. Their scope is illustrated in Figure 2.

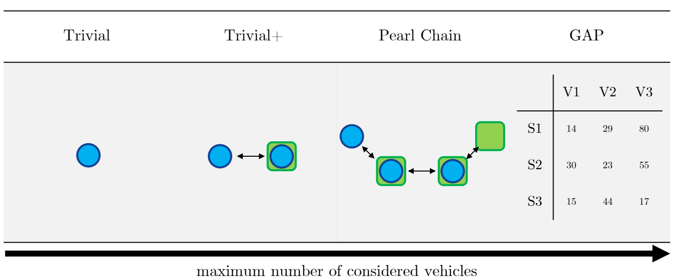

Fig. 2. The four allocation methods and their illustrated scope.

1) Trivial Allocation Method:

The *Trivial* allocation method combines the methods most frequently encountered in the literature review. They are mostly utilised in threshold-rules and nearest-agent-first allocations. Table III shows an overview structured by the defined key components, followed by their specification.

The triggering moment, in which the charging process is prompted, is predefined as the moment when the battery falls below a certain SOC (e. g., below 15 %). As soon as the current transport tasks are completed, the AGV drives to the nearest vacant charging station and the charging process continues until the battery has reached a specific SOC (e. g., above 95 %). This process can only be disrupted by the *Availability Rules of Vehicles* (see Subsection IV-B). If a vehicle is not in the process of performing a task and all charging stations are occupied, it is assigned to a parking station. Vehicles in a parking station can be pulled out by performing a task or if their charge level falls below a specific threshold (e. g., below 15 %).

TABLE III. SCHEDULING RULES FOR THE TRIVIAL CHARGING & PARKING ALLOCATION METHOD

	Timing	*Selection Criteria*	*Duration*
Charging	Below Threshold	Nearest Station	Above Threshold / Call for Task
Parking	No Task / Above Threshold / No vacant Charging Station	Nearest Station	Above Threshold / Call for Task

TABLE IV. SCHEDULING RULES FOR THE TRIVIAL+ CHARGING & PARKING ALLOCATION METHOD

	Timing	*Selection Criteria*	*Duration*
Charging	Intermediate / Below Threshold	Minimal Costs	Above Threshold / Call for Task / Displaced
Parking	No task / Above Threshold / No vacant Charging Station	Nearest Station	Above Threshold / Call for Task

2) Trivial+ Allocation Method:

The Trivial+ allocation method is designed to be more flexible, with the help of the insights gained from the literature review. The key difference to the *Trivial* allocation method is that intermediate charging are now feasible and vehicles can be displaced from their charging stations. This requires that the vehicle which has to be allocated must be compared to a vehicle within a occupied station. A description of this method is included in the Table IV and text below.

With *Trivial+*, vehicles can now be assigned to charging stations regardless of their SOC. This introduces the concept of intermediate charging. Vehicles with a very low SOC (e. g., less than 15 %) will still be allocated exclusively and therefore with priority to charging stations.

Additionally, occupied charging stations will also be considered for allocation if the occupying vehicle has a, e. g. 25 %, higher battery charge level than the vehicle seeking a charging station. This ensures that charging stations are not occupied by vehicles that have a significantly higher battery level than those seeking to recharge. Within the parameters of *Trivial*+, the driving distance to the stations remains the most important criterion for selecting a charging station. The relevant station with the lowest costs (sum of driving distance and optional additional costs) will be assigned. For occupied stations, additional costs are imposed on the vehicle that has to vacate its current station and travel to a new one. These extra costs ensure that vehicles in charging stations are not immediately displaced at will if there is a more efficient alternative for the seeking vehicle.

The charging process is carried out until the vehicle has either reached a sufficient charge level (e. g. above 95 %), gets displaced or receives a task as soon as the charge level has reached a minimum level (e. g. above 25 %).

The allocation of parking stations is unaffected by these modifications to the methods and works the same way as described for the *Trivial* allocation method.

3) Pearl Chain Allocation Method:

The *Pearl Chain* allocation method is based on the basic principle of the *Trivial*+ allocation method. However, this allocation method not only compares the battery level of both vehicles, like the *Trivial*+, but also examines whether displacements are efficient considering the total distance in meters that the vehicles would have to travel. Furthermore, a distinction is made between two situations:

1) If the seeking vehicle has, for instance, a 40 % lower battery level than the occupying vehicle, displacement is permitted without further constraints.
2) If the seeking vehicle's battery level is, for example, between 20 % and 40 % lower than that of the occupying vehicle, displacement is permitted if the total distance travelled by both vehicles is shorter than the distance to other charging station options. The travelling effort of the vehicle that needs to charge for a potential displace is calculated as follows:

$$C = D_{V_S} + D_{V_D} + M_D,$$

where D_{V_S} represents the travelling effort of the seeking vehicle to the occupied charging station, whereas D_{V_D} stands for effort involved for the displaced vehicle to travel to another station as described below. Finally, M_D represents the potential effort required for the displaced vehicle to maneuver out of its station.
The displaced vehicle is permitted to choose between the stations listed below this paragraph. This principle prevents performance issues, by a reasonable restriction of the solution space. Therefore, the "pearl chain" has a maximum length of three vehicles (see Figure 2).
   - Vacant charging stations
   - Vacant parking stations
   - Occupied charging stations which fulfill the case described in Situation 1
3) If the seeking vehicle's battery level is not at least 20 % lower than that of the occupied vehicle, a displacement is not permitted.

4) Allocation Method based on the Generalised Assignment Problem:

The GAP finds its roots in the research field of applied mathematics [28]. This problem, in its original form, consists of a number of agents and a number of tasks. Any task can be assigned to one of the agents. The total costs arising from a solution may vary, depending on each chosen agent-task assignment [29]. The optimal solution is defined as the one that maximises the total profit by minimising the associated costs.

Our idea for charging & parking vehicles by using the GAP, is to transfer the demands (in the mathematical context *costs*) of vehicles for driving to a station into a GAP. By using this method, a number of vehicles can be assigned to a number of stations by minimising the driving effort and meeting defined constraints at the same time.

These costs can be manipulated to ensure that vehicles are being assigned, on the basis of their SOC, to the closest stations according to their, even if this means bypassing some in order to allow prioritised vehicles access to these. This mechanism ensures that vehicles of a fleet with a relatively low SOC will have lower costs for charging stations than others, and will have greater priority to access charging stations. The constraints are defined as extra costs added to the driving distance to a station in meters. These extra costs are proposed as follows:

1) An occupied charging station is only accessible to vehicles whose battery charge level is 10 or more percentage points lower than that of the occupying vehicle. The theoretical allocation of a vehicle that does not fulfill this requirement is sanctioned with a penalty cost of 10,000 units and should not be accepted by a balanced system for any reason.
2) An occupied parking station is not accessible for any seeking vehicles with a battery charge level lower than the level of the vehicle currently occupying the station. The theoretical allocation of a vehicle that does not fulfill this requirement is sanctioned with a penalty cost of 10,000 units and should not be accepted by a balanced system for any reason.
3) The theoretical allocation of vehicles, with a battery level below 30 %, to a parking station will be sanctioned with a value of 1,000 units. This ensures that such vehicles will only park if no other option is available.
4) If a vehicle is occupying a charging or parking station, maneuver costs of 7 units are added.

In our opinion, the constraints formulated above will increase the likelihood of the efficient assignment of charging and parking stations. Constraint 1 allows the assignment to

Fig. 3. Exemplary two-bin principle: the full container is facing the production line. The empty container has already been collected. Replenishment will be delivered shortly.

an occupied charging station if the occupying vehicle can be assigned to any other station and the demand vehicle's battery level is at least 10 % below the battery level of the vehicle currently occupying the charging station. Due to Constraint 4, maneuver costs are also factored into every effort undertaken by a vehicle to vacate a station. Simultaneously, Constraint 2 allows vehicles in parking stations to become displaced by others if it is beneficial to the overall system in terms of distance travelled. Constraint 3 ensures that vehicles with a battery level lower than 30 % are more likely to be assigned to charging stations than to parking stations. This was determined to ensure that the vehicles' batteries are not depleted entirely – provided that enough charging stations are in the system.

B. Availability Rules of Vehicles

The defined availability rules for vehicles constitute an interface between the task allocation and the charging & parking strategy. These rules regulate the number of vehicles available for performing tasks within the system. These rules can been amended by applying two types of constraints: hard or soft constraints.

A hard constraint cannot be disregarded for any reason. By their nature, they can be easily explained and understood. Such a constraint can be formulated as follows:

- A vehicle on the field or at a parking station is available for tasks when its SOC is above, e. g. 25 %
- If a vehicle is charging, it will become available for tasks as soon as its SOC exceeds, e. g. 70 %

Soft constraints can be modelled – for example – by manipulating costs in some manner in order to change the system's behaviour to a desired behaviour. In the presented case, where the system assigns vehicles to tasks by taking into account their distance to these and their SOC, such a soft constraint can be formulated to sanction vehicles with extra costs if they are in a charging process or only have little battery left. Such a formulation can be defined as follows:

- A vehicle incurs extra costs in addition to the travelling distance in meters to a new task if it is located at a charging station. These extra costs can be calculated for example as:

$$(-1 * SOC) + 70$$

These extra costs will be negative for vehicles with a SOC above 70 %. Therefore, the system will reward these vehicles when it allocates tasks to them. They are more likely to be chosen than other vehicles on the field or parking, even if the distance to the task is the same. On the other hand, the extra costs will be positive if a charging vehicle's SOC is below 70 %. Then, this vehicle will receive penalty costs and is therefore less likely to be considered in comparison to other vehicles with the same distance. The lower a vehicle's SOC, the higher the penalty costs and the less probable their chance of receiving a new task.

V. Experimental Environment

The model layout, as shown in Figure 4, is designed to represent a typical automotive flow production system. There are three types of warehouses designed in this layout:

1) a full goods warehouse,
2) a storage for empties and
3) a mixed storage facility that serves as a full and empties warehouse.

The full goods warehouses (1 and 2 in Figure 4) are the starting points of the intracompany supply chain. The empty dollies are collected to be prepared for reuse in Warehouse 2 and 3. In the center of the layout there are three production lines that represent a flow production. Along the production lines are work stations, also called fitpoints (see Figure 3). Every work station is supplied by a predefined warehouse at certain intervals. These intervals are determined by the number of parts stored in a dolly, the frequency at which a part is required and the cycle-time of the production line. The replenishment is carried out by using a two-bin system, an example of which is shown in Figure 3. As soon as an empty container is collected, a full one is delivered by an AGV from the warehouse. There is only space for one vehicle at each station at a time. Thus, if a second vehicle was required to enter a station that is currently occupied, it has to wait in front of it and will block the pathway for other vehicles, potentially causing delays. Parking stations are established between some fitpoints along the production line (see blue house-symbols in Figure 4). The charging stations are visualised by green dots and are placed at the end of each production line.

VI. Predicted Outcomes

During the development of the previously presented allocation methods and availability rules, we endeavoured to predict

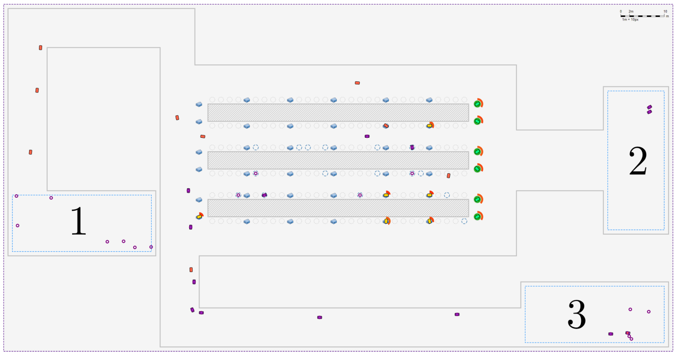

Fig. 4. Planned simulation environment consisting of three production lanes, two warehouses and one station for empty dollies.

TABLE V. PREDICTED PROPERTIES OF THE STRATEGIES

	Resource-saving	*Flexibility*	*Efficiency*	*Scalability*
Trivial	−	−−	−	++
Trivial+	0	++	++	+
Pearl Chain	+	++	+	+
GAP	++	++	+	−

the advantages and disadvantages of the resulting strategies. For this purpose, these strategies were evaluated according to the previously defined KPIs presented in Table V. It has to be highlighted that these outcomes are merely of a predictive nature. Future simulations will evaluate the strategies and their characteristics in more detail.

In summary, it is assumed that each strategy has certain strengths, but these may be disadvantageous for other characteristics like traffic density. The *Trivial* allocation method is expected to be easily scalable due to its simplicity, as this method does not require any significant computational effort. As such, any additional vehicles do not influence the individual calculation process. However, for this allocation method, the vehicles' current status, such as their position and SOC, are not compared with each other, which does not support an efficient and flexible allocation process as defined beforehand. In the *Trivial+* and *Pearl Chain* allocation method, vehicles are compared with each other in terms of their position and SOC. The resulting data are used to decide whether it is beneficial to initiate a displacement process, in which lower charged vehicles are prioritised. Furthermore, by recharging vehicles with a low SOC, the previously described loading curve, i. e. the lower the battery level, the faster the charging process, can be taken advantage of. For these reasons, positive effects in flexibility and efficiency are expected for both methods. *Pearl Chain* also compares whether certain displacements are beneficial when considering the total driving distances measured in meters. Although this requires greater computational effort of the entire system, it predicted to be more resource efficient in terms of available pathways. Due to the holistic approach of the *GAP* allocation method, a positive result is expected for the KPIs *resource-saving, flexibility, efficiency*. However, this holistic approach is expected to result in a statistically significant higher computational effort. This effort increases exponentially with the size of the system. This fact suggests that the *GAP* allocation method is unlikely to be a scalable method.

In summary, it is suggested that the combination of these *allocation methods* and *availability rules*, as illustrated in Table V, holds significant potential for any industrial setting in which AGVs are applied on a larger scale.

VII. Conclusion

In this paper, we have published our work in progress pertaining to the development of an efficient charging & parking strategy, which will reduce traffic density in a high utilised large-scale system. Alongside a state-of-the-art solution, three new methods were introduced: *Trivial+*, *Pearl Chain* and *GAP*. These methods vary in scope when calculating a decision for a specific vehicle. While *Trivial+* compares two vehicles, *Pearl Chain* is able to consider up to four vehicles for a decision and *GAP* actually takes all vehicles with a demand for a station into account. Furthermore, two types of availability rules for vehicles were proposed. Combining these *availability rules* with the various *allocation methods*, provides several strategies that could be examined in future research.

To analyse a system's behaviour and the efficiency of all strategies, a simulation study is proposed to finalise this research. Within a simulated industrial production area, each strategy will be simulated and the resulting decisions scrutinised thoroughly, and finally, the entire performance will be compared to all other strategies.

References

[1] M. t. Hompel, "Individualisierung als logistisch-technisches Prinzip (Individualisation as a logistical-technical principle)," in *Internet der Dinge in der Intralogistik*, W. Günthner and M. t. Hompel, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010, pp. 3–7.

[2] K.-I. Voigt, J. M. Müller, J. W. Veile, W. Becker, and M. Stradtmann, "Industrie 4.0 – Risiken für kleine und mittlere Unternehmen (Industry 4.0 - Risks for small and middle companies)," in *Geschäftsmodelle in der digitalen Welt*, W. Becker, B. Eierle, A. Fliaster, B. Ivens, A. Leischnig, A. Pflaum, and E. Sucky, Eds. Wiesbaden: Springer, 2019, pp. 517–538.

[3] M. Selmair, A. Swinarew, K.-J. Meier, and Y. Wang, "Solving non-quadratic matrices in assignment problems with an improved version of vogel's approximation method," in *ECMS 2019 Proceedings edited 2019*, 2019a, pp. 261–266.

[4] M. t. Hompel and M. Henke, "Logistik 4.0 (Logistic 4.0)," in *Industrie 4.0 in Produktion, Automatisierung und Logistik*, T. Bauernhansl, M. t. Hompel, and B. Vogel-Heuser, Eds. Wiesbaden: Springer Fachmedien Wiesbaden, 2014, pp. 615–624.

[5] P. Pagani, D. Colling, and K. Furmans, "A neural network-based algorithm with genetic training for a combined job and energy management for AGVs," *Logistics Journal: Proceedings*, 2018.

[6] A. Leupold, F. Senger, U. Weber, and T. Kappler, "Industrial IoT," *Digitale Welt*, vol. 2, no. 3, pp. 78–84, 2018.

[7] H. Schöning, "Industry 4.0," *it - Information Technology*, vol. 60, no. 3, pp. 121–123, 2018.

[8] H. Maier, *Grundlagen der Robotik (Basics of Robotics)*, 2nd ed., ser. Lehrbuch Studium, 2019.
[9] M. Selmair, S. Hauers, and L. Gustafsson-Ende, "Scheduling charging operations of autonomous AGVs in automotive in-house logistics," *Simulation in Production and Logistics 2019*, 2019.
[10] V. Plenk and F. Ficker, "Industrie 4.0 (Industry 4.0)," in *Digitalisierung: Segen oder Fluch*, D. Wolff and R. Göbel, Eds. Berlin, Heidelberg: Springer, 2018, pp. 29–53.
[11] Q. S. Kabir and Y. Suzuki, "Comparative analysis of different routing heuristics for the battery management of automated guided vehicles," *International Journal of Production Research*, vol. 57, no. 2, pp. 624–641, 2018a.
[12] M. De Ryck, M. Versteyhe, and K. Shariatmadar, "Resource management in decentralized industrial automated guided vehicle systems," *Journal of Manufacturing Systems*, vol. 54, pp. 204–214, 2020b.
[13] D. Fasthuber, "Integration der Ladeinfrastruktur in das elektrische Energiesystem (integration of a charging infrastructure in an electric energy system)," *e & i Elektrotechnik und Informationstechnik*, vol. 6, no. 2, p. 125, 2020.
[14] P. Keil and A. Jossen, "Charging protocols for lithium-ion batteries and their impact on cycle life—an experimental study with different 18650 high-power cells," *Journal of Energy Storage*, vol. 6, pp. 125–141, 2016.
[15] W. Shen, T. T. Vo, and A. Kapoor, "Charging algorithms of lithium-ion batteries: An overview," in *2012 7th IEEE Conference on Industrial Electronics and Applications (ICIEA)*. IEEE, 2012, pp. 1567–1572.
[16] D. U. Sauer, G. Fuchs, B. Lunz, and M. Leuthold, "Technology overview on electricity storage - overview on the potential and on the deployment perspectives of electricity storage technologies."
[17] T. Sasaki, Y. Ukyo, and P. Novák, "Memory effect in a lithium-ion battery," *Nature materials*, vol. 12, no. 6, pp. 569–575, 2013.
[18] E. Rahimzei, K. Sann, and M. Vogel, *Kompendium: Li-Ionen-Batterien im BMWi Förderprogramm IKT für Elektromobilität II: Smart Car – Smart Grid – Smart Traffic, Grundlagen, Bewertungskriterien, Gesetze und Normen*. VDE Verband der Elektrotechnik: Frankfurt a. M., 2015.
[19] N. V. Reinfeld and W. R. Vogel, *Mathematical Programming*, Prentice-Hall, Englewood Cliffs, 1958.
[20] H. W. Kuhn, "The hungarian method for the assignment problem," *Naval Research Logistics Quarterly*, vol. 2, no. 1-2, pp. 83–97, 1955.
[21] M. Selmair, V. Pankratz, and K.-J. Meier, "Efficient task prioritisation for autonomous transport systems," in *ECMS 2020 Proceedings edited by Mike Steglich, Christian Mueller, Gaby Neumann, Mathias Walther*. ECMS, 2020, pp. 322–327.
[22] M. Ebben, *Logistic control in automated transportation networks*. Enschede: Twente Univ. Press, 2001.
[23] T. Kawakami and S. Takata, "Battery life cycle management for automatic guided vehicle systems," in *Design for Innovative Value Towards a Sustainable Society*, M. Matsumoto, Y. Umeda, K. Masui, and S. Fukushige, Eds. Dordrecht: Springer Netherlands, 2012, vol. 171, pp. 403–408.
[24] B. Zou, X. Xu, Y. Gong, and R. de Koster, "Evaluating battery charging and swapping strategies in a robotic mobile fulfillment system," *European Journal of Operational Research*, vol. 267, no. 2, pp. 733–753, 2018.
[25] Q. S. Kabir and Y. Suzuki, "Increasing manufacturing flexibility through battery management of automated guided vehicles," *Computers & Industrial Engineering*, pp. 225–236, 2018b.
[26] D. Colling, J. Oehler, and K. Furmans, *Battery Charging Strategies for AGV Systems*. Wissenschaftliche Gesellschaft für Technische Logistik, 2019.
[27] X. Zhan, L. Xu, J. Zhang, and A. Li, "Study on AGVs battery charging strategy for improving utilization," *Procedia CIRP*, vol. 81, pp. 558–563, 2019.
[28] H. Kellerer, U. Pferschy, and D. Pisinger, *Knapsack problems: With 33 tables*, 1st ed. Berlin: Springer Berlin, 2010.
[29] L. Özbakir, A. Baykasoğlu, and P. Tapkan, "Bees algorithm for generalized assignment problem," *Applied Mathematics and Computation*, vol. 215, no. 11, pp. 3782–3795, 2010.