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# Optimal scheduling of AGVs in a reentrant blocking job-shop

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**Abstract**

This work presents a mixed integer linear programming (MILP) formulation to find an optimal solution to a small instance of the complex scheduling problem in a make-to-order production. Minimizing the make span, the MILP generates the optimal schedule for the autonomous guided vehicles (AGVs) in a blocking reentrant job shop environment with different jobs. Feasible schedules for the machines and the AGVs are generated from different sized instances to evaluate the limits of the mathematical model. These results are compared to a priority rule based dispatching system, evaluated with a discrete event simulation. The comparison leads to the insight, that on the one hand optimal solutions cannot be calculated for most real world scenarios due to the complexity and on the other hand the application of a standard dispatching rule lead to poor performances neither of the technics are satisfying the need to generate an appropriate schedule. As a result possible solutions are presented.

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*Keywords:* Milp; Blocking job shop; Agv; Make-to-order.

## 1. Introduction

New challenges to the production planning and scheduling are rising due to the application of cyber-physical systems. Small and medium sized businesses have to cope with the need to realize an efficient one piece flow. To be flexible, these businesses usually organize their production as job shop environment. Auffermann et al. [1] and Thoben et al. [2], state that in any cyber physical system, transportation systems will play an important role. Knowing that every production system in the future will need a transport system which is more complex than current ones, there is a need for new methods to tackle the AGV scheduling problem. To move, buffer and store raw material as well as work-in-progress, material handling systems are used. Those instances are called Job Shop Problem with Material Handling (JSP-MH) or JSP with Transportation (JSP-T). In this work, the problem of Job Shop Scheduling with Autonomous Guided Vehicles (JSP-AGV), taking into account the type and count of robot systems, picking up materials after an operation is completed and providing it to the next machine, is considered.

In Section 2 the problem of a blocking job shop environment is explained and the relevant literature is briefly discussed. Section 3 is presenting the scenario used in further research. In Section 4 this paper presents two approaches to the scheduling of an AGV in a blocking job shop environment. On the one hand the optimal solution is calculated with Gurobi solving a mixed integer linear model, on the other hand a heuristic approach (priority rule based dispatching system) is used for scheduling. The latter evaluated in a discrete event simulation. The results are compared which is leading to section 5, presenting the outlook and conclusion.

## 2. Problem Description

Modelling regular job shops, infinite buffers between machines are considered on both sides of the machines. In that case a job shop can be described as a set of independent jobs $J = \{J_1, J_2, \ldots, J_n\}$which has to be processed on a set of m machines with $M = \{ M_1, M_2, \ldots, M_n\}$. $J_i$ is an element in J, with index *i* for the job and j for the operation, describing the sequence of operations $O_{ij}$ on machine $\mu_{ij}$ being element in M with the processing time $p_{ij}$ for every operation, a set of


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machines A(j) is assigned, which can possibly process it, representing optional parallel machines. In case no buffer is present, the environment can be called blocking. A machine can no longer process any good as long it has not been cleared of the predecessor. The resulting delay adds to the processing time. This leads to a delay in all upcoming orders and is commonly found in scheduling train yards or surgeries in hospitals. Adding the problem of material movement and transport operations increases the complexity drastically. Material transport $T_{jk}$ is present if operation $O_{ij}$ is processed on machine $\mu_{ij}$ and $O_{ij+1}$ is processed on $\mu_{ik}$. Empty travel time have to be considered vice versa. With respect to the absence of buffers and the transport operations of the material handling system (MHS) a crucial dependency can be seen.

Keeping in mind, that adding the material handling system makes the scheduling process a lot more complex, various solutions have been presented using nonlinear mathematical formulations such as Zeng et al.[3] or Poppenborg et al. [4]. Given the problem being NP-hard due to the scheduling (i) of the machines and (ii) the AGVs in the job shop simultaneous [5] typical approaches are heuristic algorithms. Genetic Algorithms (GA) for the simultaneous scheduling of AGVs and a Flexible Manufacturing System (FMS) with 4 workstations have been presented by Ulusoy et al. [6]. Different hybrid approaches combining GA with other methods have been tested and proven to work well. Solutions using graphical methods are provided by Lacomme using a memetic algorithm with non-oriented disjunctive graphs and Zhang using a shifting bottleneck procedure based on a disjunctive graph [7, 8].

Using decentral approaches to the scheduling problem, agents can decide for their own, which job to take next. Priority Dispatching Rules (PDRS) can take into account single or multiple factors to provide a suitable solution. Furthermore it has to be mentioned, that the performance of PDRS for multi-stage environments differs massive from single machine systems regarding the given environment, product mix and product recipe. Based on improving computation power, new rules will be combining known effects of rules and evaluate the behavior for multi-product real world scenarios. In the near future, dispatching rules will use up- and downstream information of machines [9]. Different methods have been tested to generate new combinations of PDRS evaluating those with discrete event simulation [10]. Scholz-Reiter et al. [11] presented a solution for general dual resource constrained problems. Depending on external factors such as machine and operator utilization the same rule yields different results to the same problem.

Simple rules have been used for decades such as shortest travel time (STT) choosing the vehicle with the shortest path to the destination or maximum queue size (MQS) dispatching the AGV to the station with the number of loads in the output buffer, generating feasible but inefficient plans for the AGVs.

This results in the need for better rules taking into account more information and the prevention of potential deadlocks. Usually multi attribute rules are considered for these circumstances, for example the simple additive weighting methods (SAWM). To improve this, dynamically weighted attributes can be taken into account, such as modified additive weighting method (MAWM). The relation between operation and AGV is calculated considering different factors such as travel distance, or system utilization [12]. An extensive review has been done by Kim et al.[13], presenting different rules such as modified first come first serve, most significant move or balanced work load. Their work compared the given rules depending on storage capacity, fleet size, process/transport ratio and system utilization. As a result they present a balanced workload approach for scenarios with small buffers, where storage space is a critical resource.
Other approaches consider different factors which are multiplied with dynamically adjusting weights taking the overall system status into account. These relations are calculated as a utility value which can be compared [14].

As optimization criteria in general, the minimization of the make span is sufficient for the comparison of models [5]. On the other hand the minimization of tardiness and flowtime can be criteria as well Fazlollahtabar et al. [15]. In industrial environments the cycle time is an important factor. Combinations of all these factors are possible, considering multi objective optimization.

## 3. Scenario

In this paper an environment which can be classified as

$$J6, R2 \mid prec, blocking, t_{jk} = t_{kl}, t'_{kl} \mid Cmax$$

using Graham Notation [16] enhanced by Knust [17] is considered. In small and medium sized companies, this environment is commonly found. Furthermore this layout can be used for flexible manufacturing systems (FMS) as well. Last but not least, this scenario is used for RoboCup Logistics League [18].

The products take a certain route (grey and black lines represent different orders), defined by the product type given at the first entrance into the shop. In the Fig. 1 the products visit four machine groups (MG 1-4) with 2 parallel identical machines in the machine groups one (1) and three (3). Process time is depending on the product type and machine group. Machine breakdown, pause, shifts and maintenance are not considered yet.
Machines from one group cannot be substituted by another group. Two (2) robots are feeding the material to the machines.

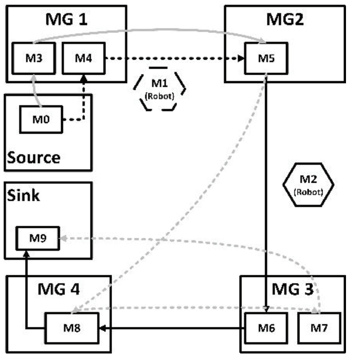


Fig. 1. In this example the 2 jobs take simple routes through the system, including 5 transport operations.

The order type defines a product specific sequence. Each robot starts an order with the pickup of a product at the transfer station and making it available to the first machine. The last operation of each order is the disposal of the product at the disposal station (sink). The transport time depends on the layout of the machines, for the given scenario a distance matrix is provided. In Fig. 1, one possible instance is presented. Transport operations with solid lines are processed by robot M2 and dashed lines are taken care of by robot M1. The movement of the AGV is not bound by any loop or network, all stations are connected through a straight line. A transport operation contains the pickup, the transport and the drop off of a product. The loading capacity of the AGV is one object per transport operation. After finishing a job, the AGV stays where it left of. In this work no dwell- and idle-points are considered.

Bilge et al. [19] presented a scenarios closely related to this for benchmarking AGV schedules, these have been used by [3, 20]. Instead of combining the load and unload station in one location, different locations, similar to [4], haven been considered for this contribution.

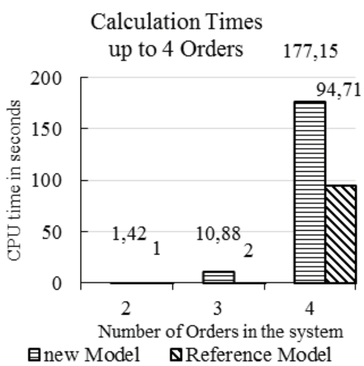


Fig. 2. Calculation time increases drastically the more orders are in the system. For more than 4 orders generating a schedule takes more than one hour.

## 4. Experimental Results

In this section the comparison of an optimal schedule and the simulation will be presented. The optimal schedule has be calculated using a mixed integer linear model, solved with Gurobi 7.0.2 [21] modelled with AMPL [22]. The discrete event based simulation is realized with AnyLogic™ 8.0.5. Its process model library is used for realization of the control logic and simulate the behaviour of the system. Process and transport time are taken from [4] and can be approximated with 300 time units on average. The P/T-Ratio can be considered 2/1, taking into account all 4 product types.

Table 1: 4 product types with different sequences and process times are used for the calculation of the schedule.

| Orders | Type | Process Time on Machine group m in Time Units | | | |
|---|---|---|---|---|---|
| J1 | 1 | MG3(10) | MG1(30) | MG2(60) | MG4(70) |
| J2 | 2 | MG2(80) | MG3(50) | MG1(100) | MG4(40) |
| J3 | 3 | MG3(50) | MG4(40) | MG1(90) | MG2(10) |
| J4 | 4 | MG2(50) | MG1(50) | MG3(50) | MG4(40) |
| J5 | 4 | MG2(50) | MG1(50) | MG3(50) | MG4(40) |
| J6 | 1 | MG3(10) | MG1(30) | MG2(60) | MG4(70) |

The general MILP has been adopted from [4], the notation has been improved using [23], considering re-entrant blocking job shop environments with hand over times. Due to the new notation the model is able to provide feasible solutions for larger instances in a shorter time. The model is used for comparison, an analysis of the exact behaviour is not part of this article. In Fig. 2 and Fig. 3 the calculation times up to six orders in the system are presented for the MILP. Fig. 2, presenting two to four orders, with the reference model providing a solution faster than the new model, Fig. 3 shows the reference model taking more time to calculate the answer with more than 4 orders in the system. The new model is able to schedule up to 5 orders optimal in less than 100 minutes CPU time. Taking into account the fact that using a commercial solver like Gurobi, calculations with 6 and more orders did not find an optimal solution after 48 hours, the time limit for all further calculations is set to 120 minutes. In Fig. 4 the make span in time units from two (2) to six (6) orders are presented.

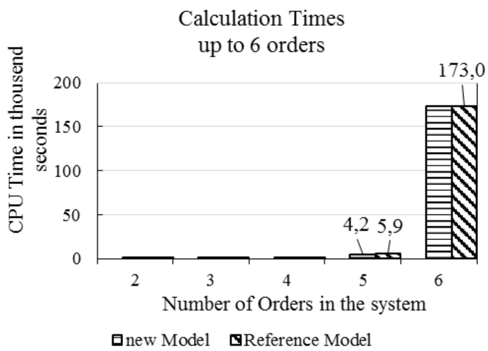


Fig. 3. Presenting the CPU time in thousand seconds, a massive raise in calculation time can be seen adding a sixth order to the problem

To be able to compare the simulation, orders are not generated randomly but a list of orders and their amount is given to the simulation (seen in Table 1). As mentioned before, machines and AGVs have to be scheduled simultaneous. For order dispatching, the priority dispatching rule FIFO has been chosen. As tie breaker the smaller index number of the job is chosen. This basic rule enables further research regarding the behaviour of the environment under different circumstances. Putting the results of the simulation into comparison to the optimal schedule calculated earlier, a statement regarding the usability of the rule in the given scenario can be made.
AGVs are dispatched on workstation initiated rule. Whenever an operation is finished, a pickup request is given. The next idle AGV will take the order, preferring the first of two AGVs as tiebreaker. Other dispatching rules for AGVs have not been implemented so far. Break down, maintenance, battery management and other dynamic events have not been considered in this work.

Table 2: The optimal solution yields much better results than the priority based dispatching rules.

| Amount Orders | MILP | | PDRS (FIFO) | Delta |
|---|---|---|---|---|
| | Cmax | CPU Time in sec | Cmax | In [%] |
| 2 | 373 | < 1 | 376 | 1 |
| 3 | 373 | 11 | 438 | 17 |
| 4 | 440 | 177 | 713 | 62 |
| 5 | 549 | 4194 | 725 | 33 |
| 6 | 644 | > 170000 | 931 | 45 |

The results show, the rule based dispatching of AGVs results in a make span, which is 17% to 62 % worse than the optimal schedule (reference Table 2). Due to its nature, PDRS cannot take in to account the future orders, like the MILP can. The incomplete knowledge of the system used by PDRS and a non-optimal dispatching policy explains the results of this study.

## 5. Outlook and Conclusion

Literature shows, that the size for FMS is usually no more than four (4) machine groups and two (2) AGVs, handling the material. This leaves the amount of orders as a crucial variable to the problem. The developed solutions provide result for online applications, up to 4 orders in the system. Considering more than 5 orders, feasible but not optimal solutions can be presented within reasonable time frames by the MILP. The usage of powerful solvers and the use of cloud infrastructure can improve the results to a certain extent.
It can be seen, that due to the complexity only small, mostly non-realistic, scenarios can be solved optimally. The MILP can be used to evaluate the performance of a typical heuristic solution (FIFO), showing a significant potential for performance improvement. Reducing the make span up to 60% motivates further research in improved advanced heuristics.

In further research, the dynamic adjustment of criteria taken into account for priority based dispatching rules has to be considered und explored. It has to be evaluated how the

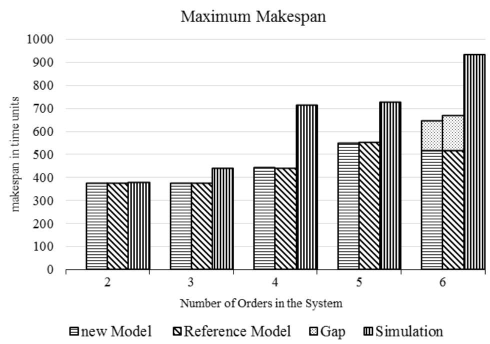


Fig. 4. Comparison show that the priority based dispatching takes up to 60% more time so complete all orders.

solutions behave in a dynamic environment representing unexpected behaviour of a plant, for example, machine failure or priority orders. Moreover, in further research other approaches to the larger instances of BJS-AGV problem, such as dynamic rule-based dispatching of AGV's, has to be considered, developed and evaluated. These new approaches, e.g. Heger et al. [24], can be assessed in comparison to the optimal solution provided by the MILP. Finally the behaviour to new jobs entering the system has to be evaluated.

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