Dynamic priority based dispatching of AGVs in flexible job shops

Heger, Jens; Voß, Thomas

Published in:
Procedia CIRP

DOI:
10.1016/j.procir.2019.02.119

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 79 (2019) 445–449

www.elsevier.com/locate/procedia

12th CIRP Conference on Intelligent Computation in Manufacturing Engineering, 18-20 July 2018, Gulf of Naples, Italy

Dynamic priority based dispatching of AGVs in flexible job shops

Jens Heger[a], Thomas Voß[a,]*

[a]*Institute for Product- and Process Innovation, Leuphana University, Volgershall 1, 21339 Lüneburg, Germany*

* Corresponding author. Tel.: +49 4131 677-5520; E-mail address: Thomas.voss@leuphana.de

Abstract

In this paper a scheduling and dispatching approach for a flexible job shop incorporating travel times of autonomous guided vehicles is analyzed. Considering multi-purpose machines, routing flexibility is also included. Knowing the calculation of the optimal schedule in this complex manufacturing system is NP-hard, multiple priority dispatching rules for machines and vehicles are compared under the influence of uncertainty. Evaluation shows that, regarding static dispatching, general improvement can be achieved applying this smart dispatching approach in flexible job shop scenarios.

Peer-review under responsibility of the scientific committee of the 12th CIRP Conference on Intelligent Computation in Manufacturing Engineering.

Keywords: Priority dispatching rules; Sequencing; Routing; Simulation; Autonomous guided vehicles

1. Introduction

Given the fact that production systems capacity is limited to the amount of material moved by the handling system, the suitable utilization of them is growing in importance [1]. This work considers a flexible job shop configuration with multi-purpose machines and autonomous guided vehicles (AGVs). These machines provide the opportunity to produce the same good with multiple process plans, allowing flexibility, increasing machine utilization and reducing flow time.

A brief literature review and the problem description are presented in chapter 2. The used scenario is described in chapter 3, followed by the details on the simulation experiment in chapter 4. The conducted simulation study provides details on the interaction of 27 different combinations of routing jobs, dispatching vehicles and sequencing of operations. The simulation based evaluation presents a feasible combination of rules that can be used for the given scenario. To prove performance the presumably best rule combination is analyzed for further details. Chapter 5 presents and discusses the results. The work is concluded with chapter 6.

2. Problem description

The general model of a job shop can be described as a set of machines $M = \{M_1, M_2, \ldots, M_m\}$, with m being the maximum number of machines in the system. Furthermore a set of independent jobs $J = \{J_1, J_2, \ldots, J_n\}$, with n being the maximum number of jobs in the system, is being processed on the machines. Each job contains a set of operations O_{ij}, with i as operation index and j the job index. Each operation is processed on a possible machine μ_{ij} being element in M. The processing time p_{ij} is given for every operation. During the scheduling a set of machines A(i) is assigned, which can possibly process O_{ij}, representing optional parallel machines. Adding the problem of material movement and transport operations the complexity increases drastically. Material transport T_{jk} is present if operation O_{ij} is processed on machine μ_{ij} and O_{ij+1} is processed on μ_{ik}. Empty travel time has to be considered if the AGV has completed a transfer operation and is called to another station.

Given the problem being NP-hard due to the scheduling of the machines and the AGVs in the job shop simultaneously [2]

2212-8271 © 2019 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the 12th CIRP Conference on Intelligent Computation in Manufacturing Engineering.
10.1016/j.procir.2019.02.119

typical approaches are heuristic algorithms. One option are Priority Dispatching Rules (PDRs) which 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 differ massively from single machine systems regarding the given environment, product mix and product recipe.

Multiple papers have considered the usage of PDRs for sequencing operations in front of machines. When using these rules for sequencing, all operations waiting in queue a priority is assigned. The operation with the highest priority is processed first. Panwalkar et al. reviewed multiple rules in 1977, presenting more than 100 dispatching rules [3]. Most commonly known example of PDRs is the sorting of operations by arrival time; the product being the first in the station is out first (FIFO). Other commonly known rules are:

- Shortest Processing Time (SPT) - the product with the shortest processing time gets processed first
- Earliest Due Deadline (EDD) – the product with the earliest due deadline gets processed first.

These rules have been used in combination with routing. Routing describes the selection of a machine from a set of alternative machines being able to process the required operation. This provides a strategic flexibility to produce a product with alternative production sequences [4]. Multiple routing rules are commonly known such as:

- Work In Next Queue (WINQ) – considering the smallest workload of jobs in queue
- Number In Next Queue (NINQ) – considering the minimum number of jobs in queue, this can be called smallest queue, and
- Least Utilized Machine (LUM) – considering the machine with least utilization

The effect of routing has been considered by multiple authors [5–8]. This must not be mistaken as the routing of the vehicle in respect to finding the shortest path to a destination!

Kim et al. reviewed single and multiple attribute dispatching rules for AGVs [10]. They used the framework provided by [11] to sort dispatching rules into two categories: Vehicle-initiated rules and work center-initiated rules. Vehicle initiated rules are applied when one idle vehicle has to be assigned to one of several outstanding jobs. Work center-initiated rules are applied when there are several idle vehicles available for a single outstanding transport demand. Simple rules have been used for decades such as:

- Shortest Travel Time (STT) - choosing the vehicle with the shortest path to the destination,
- Longest Idle Vehicle (LIV) – dispatching the vehicle that has been idle the longest time among all the vehicles and
- Least Utilized Vehicles (LUV) – dispatching the least utilized vehicle in the system endeavoring to equalize the use of all vehicles in the system

These rules have been used for generating feasible but inefficient plans for the dispatching of AGVs [12]. Their findings state that multi attribute rules can achieve substantial reduction of queue length and job completion time [10]. Le-Anh et al. state, that this could be improved even further with the consideration of reassigning and cancelation of vehicle operations[13].

Commonly known optimization criteria is the minimization of the make span, which is sufficient for the comparison of models [2]. On the other hand, the minimization of tardiness and flow time can be criteria as well [14]. Combinations of all these factors are possible, considering multi objective optimization.

3. Scenario

The scenario under investigation is classified as

$$J6, R2 \mid prec, d_i, t_{jk} = t_{kl}, t'_{kl} \mid \bar{L}_i \qquad (1)$$

using Graham Notation [15] enhanced by Knust [16]. The optimization criteria, last term in Eq.1, is the minimization pf the mean lateness of jobs ($\bar{L}_i$). Lateness, calculated by the subtraction of completion time and deadline, may not only the result of tardiness but also earliness.

The used machines have different skill sets that can be applied to process the product. It has been shown, that six machines is enough to provide enough complexity. Literature provides further examples for 8 [17] and 10 machines [18]. Instead of combining the load and unload station in one location, different locations, similar to [19], have been considered for this contribution.

Table 1. Each product type has an individual sequence of operations, which can be processed by multiple machines.

Part Type	Operation	Processing Machines					
		M1	M2	M3	M4	M5	M6
1	O11				10	10	
	O12	30	30				
	O13			60			70
	O14			60		10	70
2	O21			80			40
	O22				50	50	
	O23	100	100				
	O24			80		50	40
3	O31				50	50	
	O32			110		50	40
	O33	90	90				
	O34			110			40
4	O41			50			40
	O42	50	50				
	O43				50	50	
	O44			50		50	40

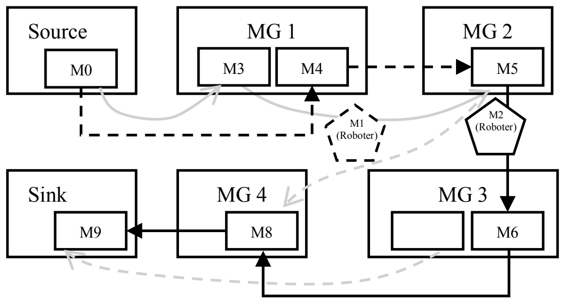

Fig. 1: Depending on the required processes and free machines products can take completely different routes.

The part type defines a product specific sequence of operations that has to be processed. The operations have to be carried out in the correct sequence, still the machine processing the operation may alternate. An example can be seen in Table 1 where the first column is describing the part type, the second describing the operation (O11 means Operation 1 for product type 1) and the third column presents the processing time of each operation on a possible machine. If no time is given, this implies an inability to process the operation on the machine. Between two consecutive steps, the product has to be moved from one machine to another.

Each robot starts an order with the pickup of a product at the transfer station and makes 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. In this scenario a distance matrix is provided. 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 off. In this work, no dwell- and idle-points are considered.

Due dates are assigned based on a general due date factor and calculated for each job i based on total work content (TWK), presented in Eq. 2. Mean process and travel times consider all product types and all distances. For the calculation of all due dates the mean process and travel times are equal for all order types and multiplied by the number of operations and material transfers, resulting in the job specific mean processing ($\bar{p}_i$) and transport times ($\bar{t}_i$).

$$d_i = s_i + k(\bar{t}_i + \bar{p}_i) \qquad (2)$$

Due Date d_i is equivalent to the start time of the job (s_i) adding the product of the due date factor (k) times the sum of mean transport time of the job ($\bar{t}_i$) plus the mean process time of the job ($\bar{p}_i$).

4. Simulation setup

In this section, the simulation based comparison of 27 priority rule combinations is presented. 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 behavior of the system.

For operation sequencing in front of a machine, the priority dispatching rule FIFO, SPT and EDD have been chosen. These basic rules enables further research regarding the behavior of the environment under different circumstances.

AGVs are dispatched on Vehicle initiated rule. Whenever an operation is finished, a pickup request is given. Three rules are tested: LIV, LUV and STT. Maintenance, battery management and other dynamic events have not been considered in this work.

For routing the products, in case of two or more suitable machines can process the same operation, the rules WINQ, LUM and SQ are used.

For comparison of the different outputs, multiple key performance indicators (KPIs) have been chosen in the experimental setup:

- Mean flow time: the average time that a job spends on the shop floor during processing.
- Mean tardiness: the average tardiness of a job during processing.

The arrival of all part types have the same probability since they are uniformly distributed. The processing times are static. The mean inter-arrival time has been chosen to be Poisson distributed, generating a system utilization of ~ 80 %. The Due-Date-Factor is set to 1.5.

To consider a steady state system 2500 jobs are processed. After a warm up phase of 500 jobs 2000 jobs are considered for the KPIs. Since job type and inter-arrival time are stochastic, 20 replications are done for each combination. All factors are summarized in Table 2.

Table 2: Parameters of the simulation experiment

Machine	Number of machines: 6
	Number of AGVs: 5
	Utilization: ~80%
Job	Job types: 4 (uniform distribution)
	Operation per job: 4
	Inter-Arrival time: 45 (poisson distribution)
	Processing time: static
	Due-date: TWK Method
Simulation	Sequencing rules: 3 (FIFO, SPT, EDD)
	Dispatching rules: 3 (LIV, LUV, STT)
	Routing rules: 3 (LUM, LWT, SQ)
	Warm up: 500 jobs
	Run length: 2000 jobs
	Replications: 20
KPIs	Mean flow time
	Mean tardiness

5. Experimental results

In this chapter, the interaction of multiple rules on each other is evaluated. For each combination of dispatching and sequencing rules a 2 by 2 matrix can be generated, using the corners for different routing rules. This can be seen in Table 4. For clarification, the recording schema is presented in Table 3 in more detail. The left upper corner represents SQ-, the upper right corner LUM- and the lower right corner represents LWT-routing. For each corner, the mean flow time and the standard deviation are recorded.

Table 3: Schema for recording the simulation experiments. All values are given in time units (TU).

	Sequencing Rule	
Dispatching rule	Shortest queue Mean flow time Standard deviation	Least Utilized Machine Mean flow time Standard deviation
		Least Waiting Time Mean flow time Standard deviation

Given the scenario, presented in Section 4, the results for different combinations of rules are presented in the given format. Table 4 summarizes the results of the simulation considering the mean flow time. The standard deviation is given and the standard error can be easily calculated. The presumably best rule combination for each combination is printed bold, in Table 4. Reading from the results, the combination of FIFO for sequencing, STT for dispatching and LWT as routing rules provide a good solution for most of the situations. Closely followed by EDD/STT/LWT and SPT/STT/LWT.

Table 4: Mean make span and standard deviation for the different rule combinations. Each corner representing one routing rule.

	SPT		EDD		FIFO	
LIV	686	979	694	1099	687	910
	4	47	5	55	7	24
		631		**635**		**626**
		5		7		6
LUV	675	963	682	1061	676	893
	6	31	8	64	7	19
		620		**627**		**619**
		8		4		5
STT	668	950	674	1054	669	883
	7	47	7	47	6	19
		610		**610**		**607**
		6		8		6

The improvement is calculated with Eq. 3, in the case of sequencing the jobs with FIFO, using STT for dispatching and LUM for routing, reducing the mean flow time by approx. 10 %. The improvement considering shortest queue routing (SQ) and Least-Waiting-Time (LWT) is even bigger, up to approx. 70 %.

$$improvement = \frac{LWT-LUM}{LWT} \qquad (3)$$

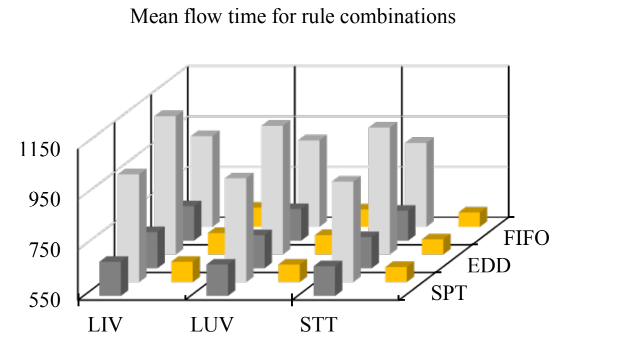

Fig. 2: The comparison of all possible rule combinations shows a significant improvement for the routing rule LWT and LUM compared to SQ, in the given scenario.

In Fig. 2, the values from Table 4 are made visual and it can be seen that in respect to the mean flow time, the LWT-rule (right lower corner of each square) is superior to LUM and SQ in all combinations. The z-scale has been edited for better readability and easy comparison. The largest values (light gray) are produced by shortest queue routing. Lower values are generated by LUM (dark grey) and the lowest values (yellow) are generated by routing products with least waiting time (LWT).

Even though the difference might by marginal, in the case of routing operations with shortest queue (SQ) and dispatching vehicles with STT the effect of sequencing operations with SPT and FIFO is contrary to routing operations with LWT. For that reason results are investigated further. Taking a closer look at the presumably best combination, the impact of the sequencing and dispatching rule mixture is considerable within the different routing scenarios. In Fig. 3, the mean value for each rule mixture with LWT routing is presented with the standard error.

Considering the mean value of FIFO/STT being lower than SPT/STT and EDD/STT during the routing, with LWT rule and the small standard error this proves better performance. This can be seen in Fig. 3. For further details, the interaction effects have to be analyzed more detailed.

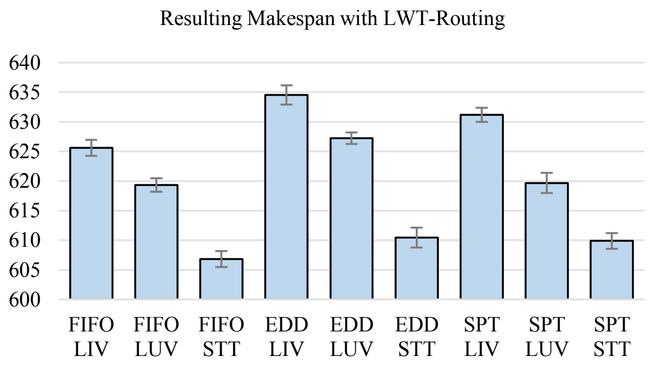

Fig. 3: Detailed comparison for the combinations of dispatching and sequencing rules show the superiority of STT as dispatching rule, in the given scenario.

6. Conclusion and outlook

The flexible job shop scenario provides a facility layout with high flexibility and utilization. Knowing that an optimal solution is NP-hard to calculate, decentral dispatching algorithms have to be used to be able to cope with dynamic system behavior and provide near optimal scheduling of operations and material handling systems within appropriate calculation time. To do so, different approaches have considered the combination of sequencing with dispatching or routing. In this study a combination taking into account all three aspects is conducted. Considering a complex scenario with 6 machines each having a specific skill set and 2 autonomous guided vehicles a simulation study considering 27 rule combinations is conducted. The evaluation of the different scenarios has shown, that the combination of LWT as routing, STT as dispatching and FIFO as sequencing rule provides good results and reduces the mean flow time in system by up to 70%, compared to other rule combinations. Within the routing rule, graphical analysis show that the present rule combination is truly best. Further evaluation has to be conducted on the behavior of the system with dynamic input, for example, if the product mix changes.

References

[1] Thoben K-D, Wiesner S, Wuest T. "Industrie 4.0" and Smart Manufacturing. International journal of automation technology; 2017; 1. p.4–16.

[2] Nouri HE, Driss OB, Ghédira K. A Classification Schema for the Job Shop Scheduling Problem with Transportation Resources: State-of-the-Art Review. In: Silhavy R, Senkerik R, Oplatkova ZK, Silhavy P, Prokopova Z (editors). Artificial Intelligence Perspectives in Intelligent Systems, Springer International Publishing, Cham; 2016. p.1–11.

[3] Panwalkar SS, Iskander W. A Survey of Scheduling Rules. Operations Research; 1977; 1. p.45–61.

[4] Pérez Pérez M, Serrano Bedia AM, López Fernández MC. A review of manufacturing flexibility. International Journal of Production Research; 2015; 10. p.3133–3148.

[5] Kaweegitbund P, Eguchi T. Flexible job shop scheduling using genetic algorithm and heuristic rules. Journal of Advanced Mechanical Design, Systems, and Manufacturing; 2016; 1. JAMDSM0010-JAMDSM0010.

[6] Doh H-H, Yu J-M, Kim J-S, Lee D-H *et al.* A priority scheduling approach for flexible job shops with multiple process plans. International Journal of Production Research; 2013; 12. p.3748–3764.

[7] Doh H-H, Yu J-M, Kwon Y-J, Lee D-H *et al.* Priority Scheduling for a Flexible Job Shop with a Reconfigurable Manufacturing Cell. Industrial Engineering and Management Systems; 2016; 1. p.11–18.

[8] Chaudhry IA, Khan AA. A research survey. International Transactions in Operational Research; 2016; 3. p.551–591.

[9] Kim CW, Tanchoco JAM, Koo P-H. AGV dispatching based on workload balancing. International Journal of Production Research; 1999; 17. p.4053–4066.

[10] Klei CM, Kim J. AGV dispatching. International Journal of Production Research; 1996; 1. p.95–110.

[11] Egbelu PJ, Tanchoco JMA. Characterization of automatic guided vehicle dispatching rules. International Journal of Production Research; 2007; 3. p.359–374.

[12] Bandyopadhyay S. In: *Intelligent vehicles and materials transportation in the manufacturing sector: Emerging research and opportunities*. IGI Global, Hershey, PA; 2018.

[13] Le-Anh T, Koster MBM de. On-line dispatching rules for vehicle-based internal transport systems. International Journal of Production Research; 2005; 8. p.1711–1728.

[14] Fazlollahtabar H, Saidi-Mehrabad M. Methodologies to Optimize Automated Guided Vehicle Scheduling and Routing Problems. Journal of Intelligent & Robotic Systems; 2015; 3-4. p.525–545.

[15] Graham RL, Lawler EL, Lenstra JK, Kan ARG. Optimization and approximation in deterministic sequencing and scheduling: a survey. Annals of Discrete Mathematics; 1979. p.287–326.

[16] Knust S. In: *Shop scheduling problems with transportation*; 1999.

[17] Kumar R. Simulation of Manufacturing System at Different Part Mix Ratio and Routing Flexibility. Global Journal of Enterprise Information System; 2016; Vol. 8 (Issue 1). p.10–14.

[18] Sharma P, Jain A. Effect of routing flexibility and sequencing rules on performance of stochastic flexible job shop manufacturing system with setup times. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture; 2016; 2. p.329–345.

[19] Poppenborg J, Knust S, Hertzberg J. Online scheduling of flexible job-shops with blocking and transportation. European J. of Industrial Engineering; 2012; 4. p.497.