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Setup-optimised Dispatching At Work Systems With Pallet Changers

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Abstract

Setup-optimised dispatching at work systems is the subject of many investigations and studies. The considerations range from developing corresponding heuristics and analysing their effects on achieving logistical objectives to practice-oriented models for estimating the impact of a specific dispatching procedure. However, despite a large number of investigations, there is still a lack of methods that consider the special characteristics of work systems with so-called pallet changers to increase the desired productivity of the machines in the best possible way. Thus, existing approaches do not consider that, in contrast to conventional work systems, a large part of the setup efforts are carried out externally, i.e., parallel with the main processing time, and focus the directly preceding (internal) setup activity at the work system.

Therefore, this paper presents a simple heuristic approach that considers the specifics of work systems with pallet changers. To show the power of the invented Pallet Changer Sequence Optimising (PSCO) rule, it is compared with an adaptation of the Minimum Marginal Setup Time (MMS) rule and the First Come First-Served (FCFS) rule. Using the tool of simulation, it is demonstrated that the developed rule clearly outperforms the MMS rule both in the area of productivity and the area of deviation of throughput times as a measure of the scheduling behaviour of the work system. The contribution thus represents a starting point for further research and optimisation of heuristics for complex machines (like CNC milling machines). It provides essential findings for practice since productivity losses on these comparatively very capital-intensive machines are particularly significant for cost-effective production.

Keywords

Dispatching; Rule-based sequencing; Heuristic; Productivity; Production Control; Simulation

1. Introduction

Optimising productivity on production machines has always been the focus of various efforts in production technology and production organisation undertakings. Thereby, the aim is to utilise the available working time of a machine (capacity) as productively as possible, i.e., to maximise the productive processing time on a machine and to minimise downtimes or unproductive times like setup times. [1–3]

Concerning production technology, e.g., new clamping systems have been developed, allowing a quick changeover of a machine, resulting in a considerable reduction of setup times and making production with smaller lots more productive and flexible [4]. A widely used method in this context is SMED (single-minute exchange of die) [5], which effectively reduces setup times. Also, the externalisation of setup activities or preparatory activities and main time-parallel setup, in general, contribute to an increase in productivity [6].

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However, in practice, setup times cannot be satisfactorily reduced cost-effective on all production machines or for every product to a preferred minimum in order to archive a high machine productivity, which is why organisational measures are also required. These include, in particular, levers that can be assigned to production planning and control (PPC), such as intelligent scheduling [7,8], lot size optimisation [9], setup-optimised dispatching at the machine [10,11] or the release of orders into production, taking setup times into account [12,13]. This publication focuses on setup-optimised dispatching at work systems [11,14] as a lever of production control.

In an investigation of a production area at a German machine manufacturer, where the potential of setup-optimised dispatching was to be evaluated, the authors observed that the existing standard models and procedures for the formation of setup-optimised sequences (see, e.g. [11]) and for the calculation of the resulting productivity potential [10] were not applicable for specific work systems. Thus, on machines with pallet changers able to do a quick changeover of the machine tables, it was observed that instead of the comparably low internal setup times due to the changing of the tables, the much higher external setup time had to be considered leading to a sort of dual-resource problem. The authors have therefore developed a new heuristic for the setup-optimal sequence formation on work systems with pallet changers, which is presented in the following.

2. Basics of Setup-optimised Dispatching

Optimising setup times using dispatching at work systems is a field of consideration in many scientific studies [14,15,11]. Thereby rule-based heuristics are generally distinguished from optimisation or machine learning-based approaches (see [16]). While the rule-based heuristics give general procedural instructions on how a sequence should be formed and thus provide a general description that can be adapted to the specific application, optimisation or machine learning-based approaches are often strongly context- or company-related. In the present work, we thus undertake a generally valid modelling of a rule-based heuristic derived from a real-world observation.

Independently of how the sequence is formed, the effect of setup time optimisation on the productivity of a work system can be attributed to two major effects. Figure 1 illustrates both effects using the so-called throughput element (see Figure 1).

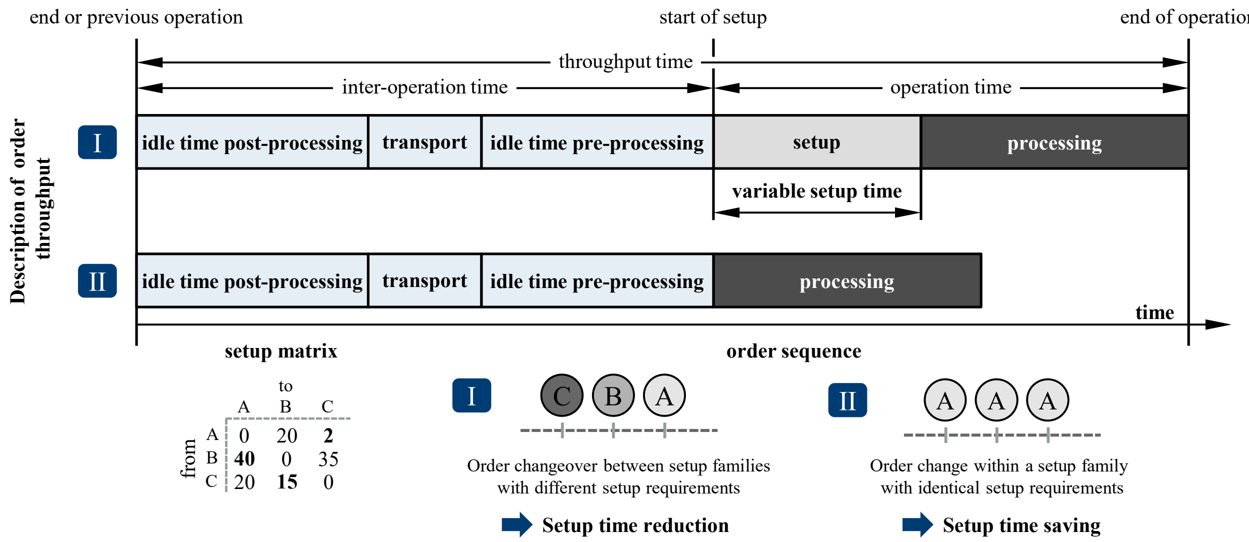


Figure 1: Comparison of Setup time reduction and Setup time saving (based on [17,18]).

On the one hand, setup times can be saved (nearly) completely (setup time savings). This effect occurs if different orders of a setup group, also called a setup family, are consolidated, whereby the setup time for processing the orders following the group's first order is (mostly) omitted (Figure 1, case "II"). On the other hand, setup times for changing between the setup groups can be sequence-dependent or group-specific (Figure 1, case "I"), which means that the average setup time on the production machine can be reduced by a corresponding dispatching rule finding a suitable path in the so-called setup matrix (setup time reduction). [19,17,10]

As an example, it can be seen in Figure 1 that the sequence formation C-B-A-(C) results in a total setup time of 57 units per cycle, while another order sequence leads to significantly longer setup times. For instance, the family sequence A-B-C-(A) would result in a setup time of 75 units per cycle.

3. Challenges of Machines with Pallet Changers

In contrast to standard work systems, production machines with pallet changers differentiate because a large part of the setup time can be externalised by carrying out the setup process for the next job on a second (or more) table(s) parallel to the processing of the current job (see also [20]). This also allows complex clamping systems to be set up without causing a high loss of machine productivity. However, in practice, it appears that the proportion of external setup time to the processing time of a job at machines with pallet changers is significantly higher than the proportion of setup time to the processing time at standard work systems. This primarily results from the fact that the production lot sizes at production machines with pallet changers are reduced due to the higher flexibility of the machine. Nevertheless, this increases the risk of larger time frames of unproductivity, especially if the order sequence is not optimised and the preparation time of the table to be set up for the next order family exceeds the available time during the processing time of the current job or family on the table currently in the machine. Furthermore, the setup time on the machine itself can only be minimally influenced, as it is mainly determined by changing the tables and initialising the order, during which the machine operator is restricted and cannot carry out any other external setup activity.

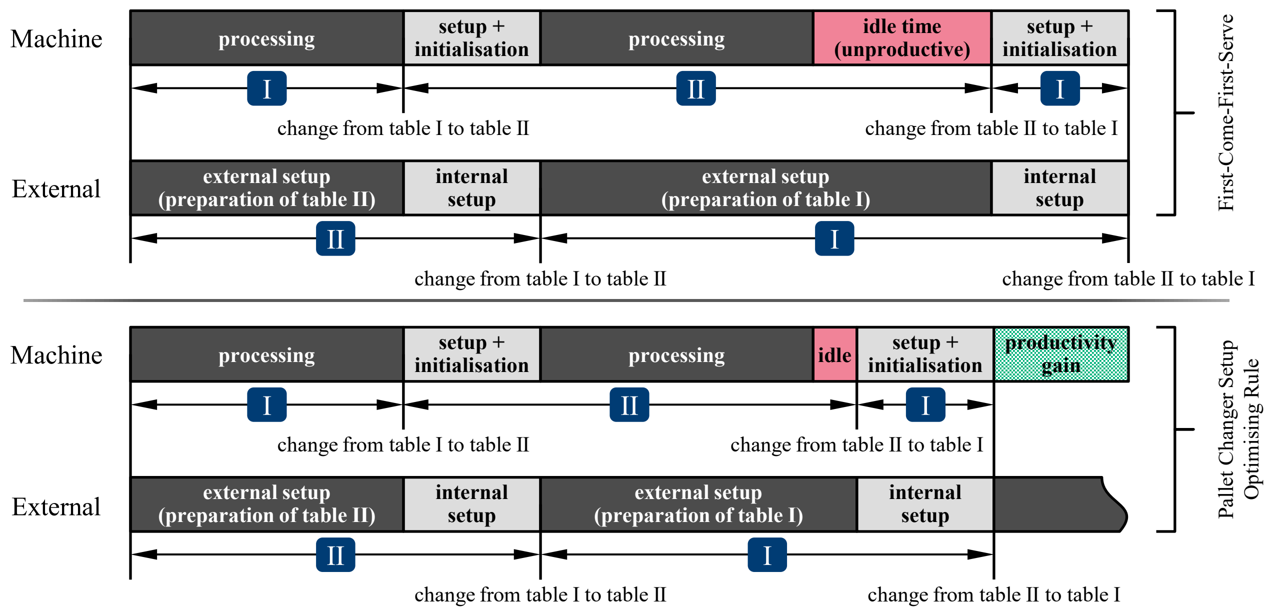


Figure 2: Enlarged throughput element for machine and table at machines with pallet changers for a) First-Come-First-Serve dispatching, b) pallet changer setup optimisation (extended according to Heinemeyer and Bechte) [18].

In order to visualise the flow of an order through production or at a work system, the already in Figure 1 used throughput element, according to HEINEMEYER and BECHTE [18], is suitable and was adopted for the case of work systems with pallet changers. Thus, Figure 2 shows the coupled throughput element for the machine and the external setup area, on the one hand, for a First-Come-First-Serve rule (FCFS) and, on the other hand, for a setup time-optimising dispatching rule. In the case of the FCFS rule, it can be seen that the machine has an unproductive idle time after processing the order on setup table II since setup table I has not yet been fully prepared. In the case of the setup time-optimising dispatching rule, on the other hand, it can be seen that this unproductive time could be significantly reduced, allowing the swapping of tables II and I to start earlier and resulting in an overall productivity gain (in the sense of reduced idle time and thus of a higher quotient of processing time to available time) equal to the green area.

4. Developing Dispatching Rules for Work Systems with Pallet Changers

To meet the special characteristics of systems with pallet changers, for which no publications could be found in literature, the (Minimum-Marginal-Setup-Time) MMS rule of [21] has been adapted for systems with pallet changers and subsequently, inspired by this, a new quotient-based dispatching rule, the (Pallet-Changer-Sequence-Optimising) PCSO rule, has been developed.

The adapted MMS and PCSO rules are presented in the following, demonstrating their function and effectiveness using an exemplary and fictitious order backlog (see Table 1).

Table 1: Exemplary order backlog to be dispatched using the First-Come-First-Serve (FCFS) rule.

Order Number	Setup Family	Setup Time External [min]	Processing Time Machine [min]	Processing Time Predecessor [min]	Productivity Loss / Idle Time [min]
1	A	60	70	---	0
2	B	120	60	70	50
3	C	100	40	60	40
4	D	30	30	40	0
5	B	120	80	30	90
6	D	30	40	80	0
7	C	100	30	40	60
8	A	60	50	30	30
9	E	80	80	50	30
				Sum	**300 Min**

As shown in Table 1, there are nine orders belonging to five setup families to produce, and a sequence has to be formed. In order to increase comprehensibility, two delimitations were made to demonstrate the effects of the dispatching rules. First, it is assumed that these nine orders have to be sequenced without any new orders being added in the meantime. Furthermore, it is assumed that the external setup time is not sequence-dependent. If this were the case, changing the sequence of orders and setup families would also change the external setup time at each decision step, making the comprehensible illustration no longer possible due to the dynamic solution area.

4.1 The adapted MMS Rule

The MMS rule, according to Arzi and Raviv [21], was adapted in such a way that the calculation of the setup time is not based on the time occurring in the machine but on the basis of the externally occurring setup time. This means that the setup time resulting from the disassembly of the clamping system of the last setup group produced on this table and the re-setting of the table for the next group must be considered. Following the original MMS rule, the setup group with the lowest quotient is selected to be set up next on the table. Equation 1 formalises the sequence decision of the adapted MMS rule.

$$R_{i,j} = \frac{TS_{i,j}}{WIPO_j} \tag{1}$$

with: $R_{i,j}$ Ratio in case of changing from setup family i to family j

$TS_{i,j}$ Setup time for switching the setup on a table from setup family i to j

$WIPO_j$ Work-in-Process of setup family j at machine in number of orders

Nonetheless, it can be deductively derived that minimising the external setup time, as it is carried out in this way, is sensible, but potential is given away because the available time during the processing of an order is not optimally used for setup activities. The effect is particularly comprehensible in the case of a large potentially available timespan being occupied by a very small setup time while the processing time of the corresponding setup group is only very short. This means that the following changeover process is likely not feasible without a loss of productivity because the setup time exceeds the available time, and the machine is idle.

Table 2 shows the order sequence for the introduced order backlog according to the adapted MMS rule.

Table 2: Exemplary order backlog to be dispatched using the adapted Minimum-Marginal-Setup-Time (MMS) rule.

Order Number	Setup Family	Setup Time External [min]	Processing Time Machine [min]	Processing Time Predecessor [min]	Ratio (see Eq. 1)	Productivity Loss / Idle Time [min]
1	A	60	70	---	---	**0**
8	A	60	50	---	---	**0**
4	D	30	30	120	15	**0**
6	D	30	40	---	---	**0**
3	C	100	40	70	50	**30**
7	C	100	30	---	---	**0**
2	B	120	60	70	60	**50**
5	B	120	80	---	---	**0**
9	E	80	80	140	80	**0**
					Sum	**80 Min**

As it can be seen in the table, the productivity loss in the example is reduced from 300 min (FCFS) to 80 min (MMS). Due to the weakness already mentioned and the fact that the process times of the individual orders or setup families are not taken into account, the example shows that the change from setup group D to C is associated with a productivity loss of 30 minutes and the shift from C to B with 50 minutes.

4.2 The PCSO Rule

In order to further reduce the sum of productivity losses, the PCSO rule was developed in such a way that instead of minimising setup time, it strives for the best possible utilisation of the potential of the available time during machine processing. For this purpose, the divisor was changed accordingly, and the procedure rule was set up so that the setup group is always spanned next to whose quotient corresponds closest to the ideal factor of 1 but is less than or equal to 1. If this is not possible, the group with the lowest ratio is taken.

$$R_{i,j} = \frac{TS_{i,j}}{WIPO_p * TP_p} \tag{2}$$

with: $R_{i,j}$ Ratio in case of changing from setup family i to family j

$TS_{i,j}$ Setup time for switching the setup on a table from setup family i to j

$WIPO_p$ Work-in-Process of setup family p actually in processing in number of orders

TP_p Processing time per unit of setup family p

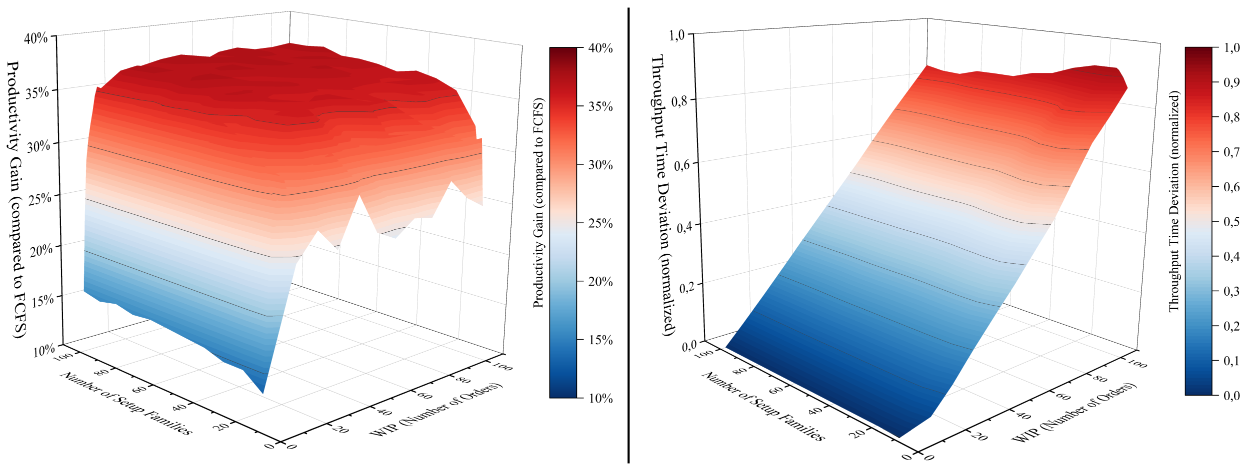
Table 3: Exemplary order backlog to be dispatched using the Pallet-Changer-Sequence-Optimizing (PCSO) rule.

Order Number	Setup Family	Setup Time External [min]	Processing Time Machine [min]	Processing Time Predecessor [min]	Ratio (see Eq. 2)	Productivity Loss / Idle Time [min]
1	A	60	70	---	---	**0**
8	A	---	50	---	---	**0**
2	B	120	60	120	1	**0**
5	B	---	80	---	---	**0**
3	C	100	40	140	0,714	**0**
7	C	---	30	---	---	**0**
4	D	30	30	70	0,429	**0**
6	D	---	60	---	---	**0**
9	E	80	80	90	0,889	**0**
					Sum	**0 Min**

As Table 3 shows, the application of the PSCO rule in the example leads to the fact that the productivity loss can be reduced to 0, and thus no unnecessary idle times occur on the machine. It can also be seen that the PSCO rule benefits, in particular from the fact that there is no proportional relationship between setup times and processing times of orders and that the quotients of setup to processing time fluctuate strongly. Thus, it can be assumed that the greater the fluctuations in this quotient, the more likely this sequence rule leads to productivity gains.

5. Assessment via Simulation

In order to investigate the strength and functioning of the PSCO rule in more detail and to obtain initial conclusions about sensitivity, a simulation study was carried out. In the simulation study, the performance of the PCSO rule was compared with the adapted MMS rule and the FCFS rule in a setup-intensive production environment. In the simulation, a constant WIP level (work-in-process) of orders was created using a CONWIP order release [22]. The incoming orders were randomly assigned to a setup group known when the order arrived in the system. The setup time matrix was assumed to be random according to [8], and the mean setup time was set equal to the mean processing time (2 hours). The variation coefficients of the processing times were set to 0.5 and those of the setup times to 1 for the dispatching rule comparing simulation series. The WIP level and the number of setup families varied in different test series. For simplification, the time designated as internal setup in the throughput element in Figure 1 was not regarded since dispatching does not influence it. The simulation was carried out using the software Plant Simulation.



a) Productivity Gain PCSO rule (compared to FCFS)

b) Throughput Time Deviation PCSO rule

Figure 3: Simulation results for the PCSO rule regarding productivity gain and throughput time deviation.

Figure 3a) shows the productivity gain of the PCSO rule compared to the FCFS rule, showing how significant productivity gains can be observed already at low stock levels. At the same time, it is evident that these productivity gains increase strongly with the work-in-process (WIP) of the work system and also increase slightly with the number of setup families. A plateau forms at about 37%. The right part of the figure (Figure 3b))shows the expected result according to [10] that productivity gains are bought with an increase in throughput time dispersion, which is linearly related to the work-in-process. As usual, for a setup-optimal sequence strategy, it becomes apparent that the operators have to accept scattering in the throughput time if they want to achieve productivity gains.

To further investigate possible influencing variables, the productivity gain of the PCSO rule was examined as a function of the standard deviation of the setup time and the mean setup time, the mean processing time (2h) and its dispersion (1h) were left constant. The number of setup families and the work-in-process have been varied from 2 to 100 in steps of 2. The productivity gain was then summarised for an entire series.

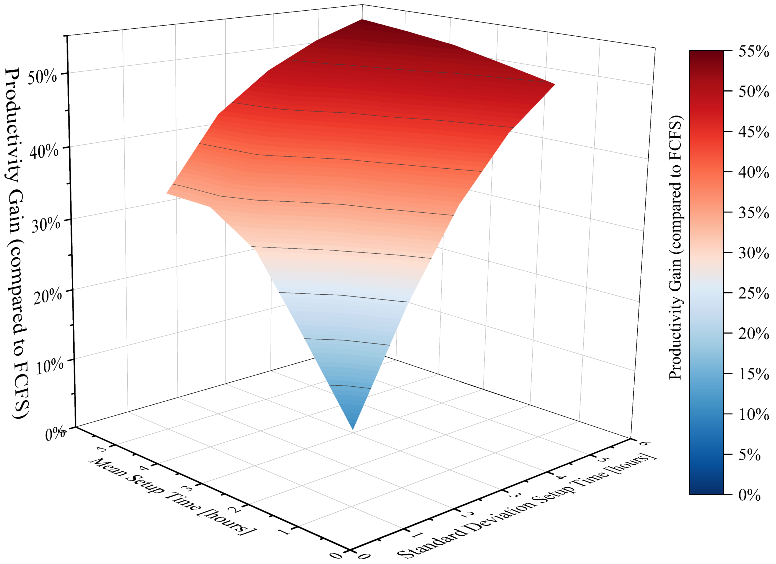
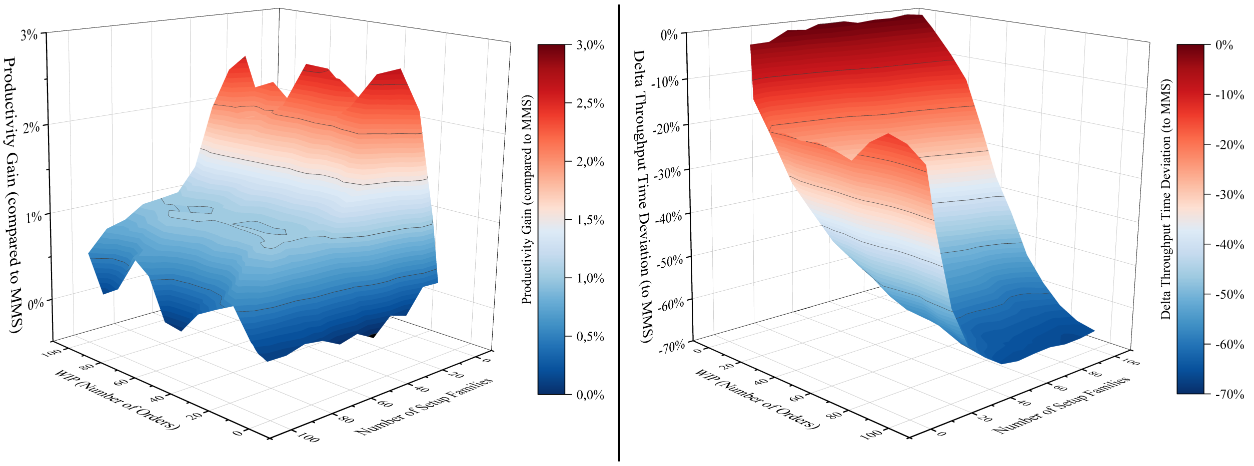


Figure 4: Sensitivity analyses of the productivity gain of the PCSO rule compared to the FCFS rule.

Figure 4 shows the resulting sensitivity of the productivity gain. As can be seen, the productivity gain increases both with increasing mean setup time, i.e., an increasing quotient of mean setup time to mean processing time, and with a growing scattering of the setup times. Both effects are plausible because, as already mentioned, a larger dispersion of setup times leads to a higher variation of the quotient between setup and processing time of the single orders, which increases the effect of the PCSO rule on the productivity gain. The potential of achieving productivity gains rises with an increase of the mean setup time.

In addition to comparing the PCSO rule with the FCFS rule and the sensitivity analysis, a comparison was also made with the adapted MMS rule, shown in Figure 5. Figure 5a) compares the productivity gain achieved by the PCSO rule with the MMS rule. It can be seen that, especially in the case of fewer setup families, the PCSO rule exceeds the productivity gain of the MMS rule, but the potential decreases as the number of setup families increases. This can be explained by the fact that with an increasing number of setup families and a randomly distributed setup time matrix, it becomes more likely for the MMS rule to find a setup family with a very low setup time so that the probability of productivity losses decreases accordingly. However, the series of experiments also show that the PCSO rule never performs worse than the MMS rule and is, therefore, preferable in terms of productivity.



a) Productivity Gain PCSO rule (compared to MMS)

b) Delta Throughput Time Deviation PCSO rule (to MMS)

Figure 5: Simulation results comparing PCSO and MMS rule on a) productivity and b) throughput time deviation.

Figure 5b) shows how the dispersion of the throughput times between the PCSO rule and the MMS rule behave. First, it is surprising that the variation induced by the PCSO rule is clearly smaller than that caused by the MMS rule and that the effect increases with a larger work-in-process as well as with a larger number of setup families. However, the result can be explained by the circumstance that the PCSO rule actively considers the work-in-process currently in processing in its decision, whereas the MMS rule does not. Thus, while the MMS rule results in orders being selected very randomly from a scheduling point of view resulting in a higher Throughput Time Deviation, this effect is dampened by the PCSO rule's consideration of the work-in-process.

In summary, the PSCO rule outperforms the MMS rule both in the area of productivity and in the area of throughput time variance.

6. Conclusion and Outlook

This contribution aimed to show the potential of an adapted heuristic for setup time-optimising dispatching at work systems with pallet changers. Although the presented heuristic is relatively easy and still has much potential for further optimisation, the analyses already show immense potential in the area of higher productivity and reduced scattering of throughput times. Nevertheless, additional optimisations of the heuristics are conceivable, for example, through the tactical splitting of large lots or setup families and the removal of the "rigid" quotient rule.

A significant limitation of the application of the developed method is the availability of all necessary data. In industrial projects, the authors experienced that standard times are often not reliably available, especially for the personnel (external) setup times and that a setup time matrix cannot be created. Nevertheless, it should be noted that the procedure is also possible without the existence of a complete setup time matrix with fixed setup times per setup group, analogous to [19], with corresponding potential changes. Besides the specific application for work systems with pallet changers, the developed approach can also be transferred to other problems, such as dual-resource problems. Further research should be undertaken in particular to investigate the effect of the PCSO rule on the productivity gain and the throughput time variation in more detail as a function of the influencing variables and to determine the impacts as quantitatively as possible.

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Biography

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