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THE IMPACT OF DOOR LEAF PARAMETERS ON THE EFFICIENCY OF THE AUTOMATED TECHNOLOGICAL LINE

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ABSTRACT

The automated intelligent technological line for the mass production of door leaves enables mass customization using unique QR codes. The IT control system dynamically adjusts the processing parameters to the currently processed door leaf, allowing the line modules to fine-tune the settings. Door leaves categorized by colour, width and the presence of a rebate were tested in terms of efficiency. The time elapsed between the cycle completion on the line of two consecutive leaves in a series and the time changes depending on the product parameters are measured in the experiment. The results showed a significant impact of item classification on line efficiency. Colour sorting halves the takt time while sorting by width and the presence of rebates results in an efficiency increase of more than six times with the same technology and high quality.

Keywords: wooden door manufacturing; product classification; takt time; colour finish; door leaf width; door leaf rebate.

INTRODUCTION

The modern market for construction joinery is becoming increasingly demanding daily, emphasizing efficiency, sustainable development, and process optimization. Along with changing customer requirements, the range of products with non-standard features increases significantly. The consequence is the necessity to produce products in small batches or even single items (Patel and Shah, 2014). In the case of manufacturing companies, customization is an effective solution in commercial competition and strengthening the existing competitive advantage (Zhao *et al.*, 2018). It allows producers to increase customer satisfaction, retention, and, finally, loyalty (Kwidziński *et al.*, 2022). To respond quickly to changing trends and consumer preferences, a company with a diverse product offering must implement optimal organization, planning and scheduling, and control of automated production lines (Patel and Shah, 2014; Taifa and Vhora, 2019).

Optimal resource utilization enhances the enterprise's competitiveness, reduces costs, and minimizes environmental impact. Decreasing energy consumption is becoming increasingly important, and efficient use of machinery and production lines is crucial to achieving this goal. Maintaining a short time in manufacturing operations is one of the crucial factors influencing production efficiency.

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Improvement of efficiency in the manufacturing industry should focus on shortening cycle times centered on the balance of man, machine, materials, methods, management, and environment, also called 4M 1E (Ebrahim *et al.*, 2015). Even claim that the duration of the production cycle is one of the most important "economic and technical indicators" in assessing the production process's performance (Klarin *et al.*, 2016). It is worth noting that (Taifa and Vhora, 2019) provide a systematic review of the various methods deployed for cycle time reduction, pointing out advantages to be achieved. Moreover, it outlines the relationship of critical time loss elements to existing production performance measures such as agility, fitness, flexibility, leanness, responsiveness, and sustainability (Ebrahim *et al.*, 2015).

Ensuring the shortest possible production cycle requires conducting research and systematic production control. By analyzing the impact of various factors on production line efficiency, we can refine processes, minimize time and material losses, and increase overall productivity. Previous research shows that variable factors such as finish colour significantly affect processing time in door leaf production (Kwidziński *et al.*, 2024). However, to gain a comprehensive understanding and further improve processing processes, it is necessary to expand the scope of analysis and consider additional factors influencing efficiency. In this context, our research focuses on increasing the analysis of the impact of various features on the efficiency of the TechnoPORTA production line. The study aimed to test the hypothesis that the order of processed door leaves differing in colour, width, and the presence of a rebate affects line performance. In addition, identifying which of these variable factors is most significant in classifying parts during the production of door leaves on an automated customization line. The results obtained can be used to develop a strategy to optimize the production process by reorganizing it.

MATERIALS AND METHODS

The operational principle of the TechnoPORTA technological line

The TechnoPORTA line is designed for processing narrow surfaces of door leaves. It consists of segments, including the base edge milling module, pre-and post-processing edge milling module, edge band application module, press-down sections, corners, edge processing module, and rebate milling module. Each door leaf is marked with a QR code containing information such as cycle number, dimensions, finishing colour, family, model, hardware type, and other necessary specifications for processing adjustment flawless transportation. Before each piece is fed into the line, the posted QR code label is scanned, and with the information sent to the machines, the line settings are automatically adjusted. To finish, each door leaf must undergo at least three cycles on a TechnoPORTA line. The narrow top surface of the door leaf is processed in the first pass, and in the subsequent two passes, the narrow side surfaces are processed (Kwidziński *et al.*, 2022). Each adjustment of processing parameters presents a challenge due to machine tool changeover. Changing the finishing colour of narrow surfaces, such as edge colour, between successive pieces requires additional time for the technological line to heat up or cool down the lamps to the appropriate temperature. The cooling process is not additionally assisted. Successively arranged door leaves with different widths necessitate a change in the positioning of bases on the machine, while transitioning from processing items without rebates to those with sealing grooves involves activating another unit of the TechnoPORTA line.

Tested material

The study was conducted on door leaves with a panel structure, which is part of regular production. The narrow surfaces were finished with a 1 mm thick ABS edge band. Four subgroups were examined. The first comprised elements with identical processing parameters, while the consequent three consisted of groups with elements having diverse line-setting requirements. For the tests, machining times were measured for 72 door leaves, each of which underwent all three machining cycles, resulting in 216 controlled cycles. Mixed sets were chosen so that the products differed only in one parameter affecting line settings at a time – colour, width, or alternating rebated, shown in Table 1, and their visualizations are presented in Fig. 1. Door leaf samples from different groups were arranged alternately on pallets. Sorted sets had identical processing characteristics.

Tab. 1 A variant of door types is used for testing.

Variant tested	Quantity tested [pieces]	Tested door leaf	
		Model	Colour
Sorted	5 5 5 5	Opal 37 dB Extreme RC2 Extreme RC2	Wood White Milano 1 Natural Oak
Change of colour	10 10	Extreme RC2 Extreme RC2	Milano 1 Natural Oak
Change of width	10 10	37 dB Opal	White Wood
Alternating rebated	6 6	Opal Air	Wood Mint

SSWZS Opal Wooden | SSAKS 37dB White | SSARS Extreme RC2 Milano 1 | SSARS Extreme RC2 Natural Oak | SSPTS Air Mint

Fig. 1 Visualization of door types used for testing.

Research methodology

The time measurements used in the article were conducted at a constant line feed rate of 20 m/min. A stopwatch with an accuracy of 0.01 s was employed for precise time monitoring. The measurement procedure involved timing between the completion of processing subsequent products. The time measurement started when the first door leaf left the line and ended when the subsequent door leaf left the line. As a result, for a series containing n elements, n-1 interval time measurements were obtained for the subsequently processed element from the TechnoPORTA line.

The measured times were categorized into four sets based on the characteristics of the door leaves: sorted – with identical processing parameters, with colour change, width change, and alternating with or without rebate. The measurements were used for calculations. Measurements during line downtime were excluded. Utilizing the formula for the arithmetic mean (1):

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{1}$$

For each trial, the standard deviation was also calculated using the formula (2):

$$s = \sqrt[2]{s^2} = \sqrt[2]{\frac{1}{n-1}\left(\sum_{i=1}^{n} x_i^2 - n \cdot (\overline{x})^2\right)} \tag{2}$$

Where:
s – the standard deviation,
n – the total number of elements in the set,
x_i – the individual argument,
$\overline{x}$ – the mean.

The numbers for “sorted series in batches of 20 pieces” used in Figure 5 were calculated using the following formula (3):

$$D = \frac{1}{3} \cdot \frac{h \cdot 3600}{\overline{x_s} + \frac{\overline{x_{us}}}{e}} \tag{3}$$

Where:
D – the number of processed doors in h hours,
h – the number of working hours,
$\overline{x_s}$ – average time for sorted series,
$\overline{x_{us}}$ – average time for unsorted series
e – elements per pallet.

RESULTS AND DISCUSSION

The average takt time for the subsequent product to come off the technological line, depending on the door leaf variant tested is shown in Figures 2-4. In the series of sorted door leaves, the average time between the completion of processing of two subsequent items was 10.06 seconds. For products arranged alternately in terms of finish colours Milano 1 and Natural Oak, the average takt time was 17.58 seconds. The batch of door leaves with alternating rebates achieved an average takt time of 59.58 seconds. In the group of doors with variable widths, the average time between the exit of products from the line was 64.21 seconds. These values are depicted in the corresponding graphs, Fig. 2-4, illustrating the variability of takt time for the subsequent product depending on the difference in parameters of the previous door leaves.

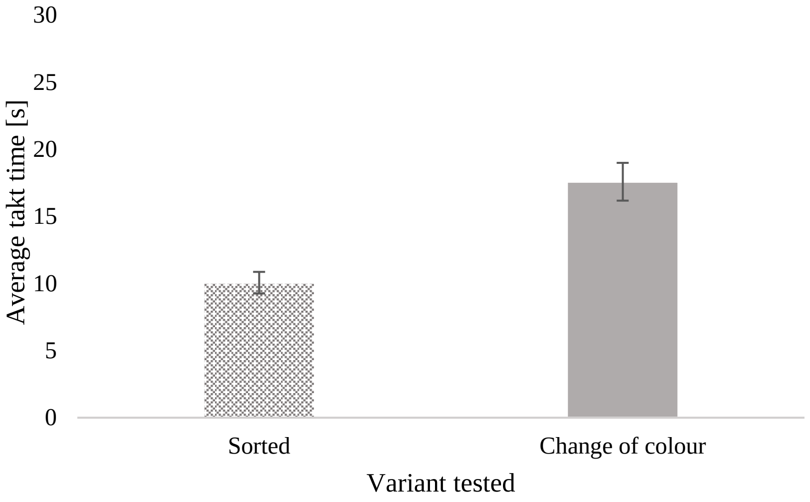

Fig. 2. The takt time for the subsequent door leaf for the sorted series and colour changes series.

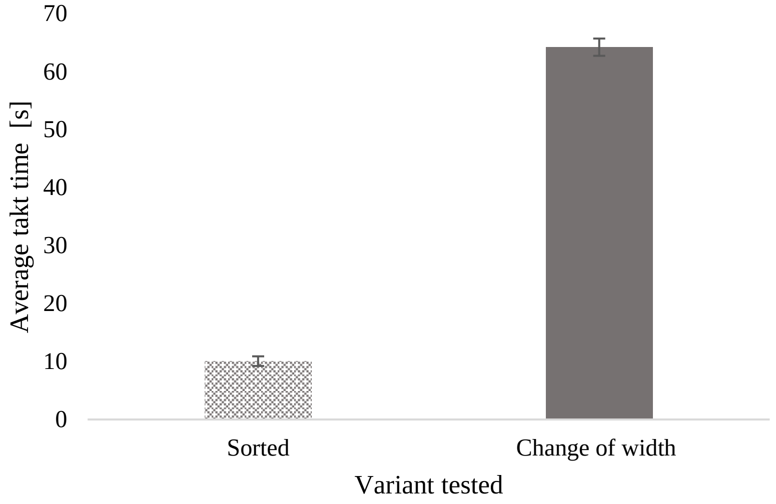

Fig. 3. The takt time for the subsequent door leaf for the sorted series and width change series.

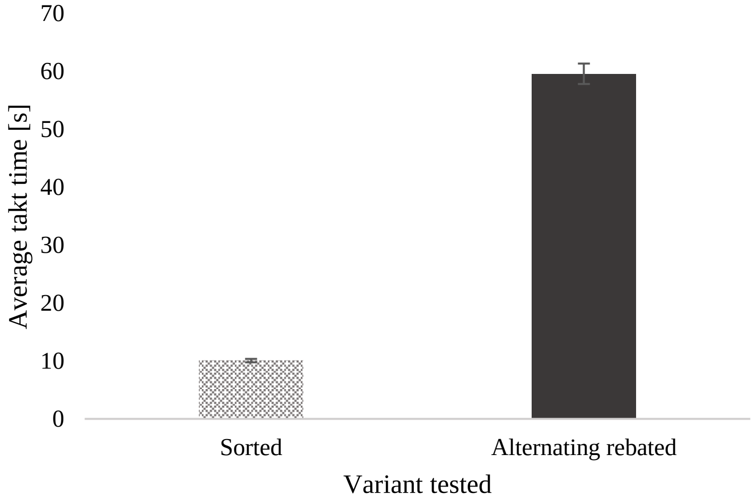

Fig. 4. The takt time for the subsequent door leaf for the sorted series and alternating rebated series.

Fig. 2 presents the time required to exit the subsequent element from the technological line in a series of aspects with colour change and a series of sorted products. These values differ approximately twice, confirming observations from previous studies (Kwidziński *et al.,* 2024). Subsequent graphs, Fig. 3 and Fig. 4, illustrate the differences in selecting door leaves and arranging them alternately in terms of width and present rebated. The time differences between these two comparisons are similar. The processing time of a door leaf with a width different from the previous one results in a sixfold longer takt time. This is a very significant value, especially in mass production. Considering that each door leaf must undergo 3 processing cycles on the TechnoPORTA line, we can simulate production forecasts for an 8-hour shift for each of the four possibilities of arranging the order of door leaves. Dividing the interval time by the threefold average time obtained in the previous calculations (Fig. 2-4) gives an increase in the number of fully processed doors in successive working hours. These results allow us to estimate not only the daily efficiency of the line but also the potential losses resulting from less optimal processing sequences. The calculation omitted the processing time of the first element from entering to exiting the line. This would be a value equal for all four series without a tangible impact on the results, hence the simplification of the calculations. The results of the simulations are illustrated in Fig. 5, showing the key differences in efficiency depending on the batch preparation strategy.

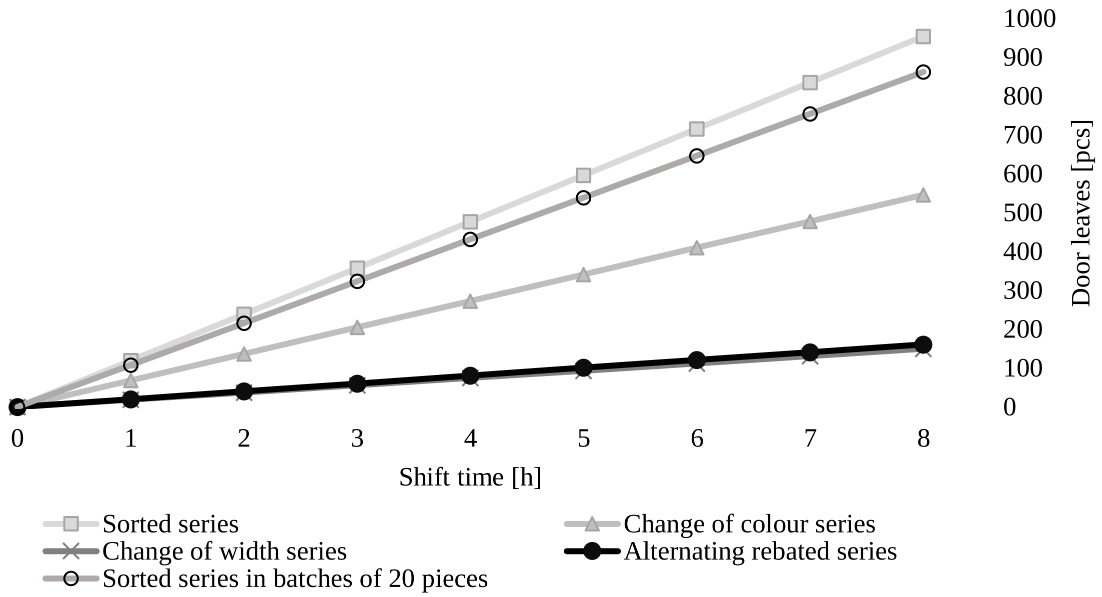

Fig. 5. Increase in the number of door leaves during an 8-hour shift.

In a continuous, eight-hour processing of elements with identical characteristics, the line can produce 954 doors. Maintaining only the same width and the consistent presence of the rebate reduces the line's efficiency to 546 doors. In the case of producing a series of door leaves with the same finishing color but varying rebate presence or change of width, the line can produce 161 and 150 door leaves, respectively, during one shift. The data shows this is six times less than the ideal situation where we can process leaves with fixed characteristics affecting the machine settings. Any additional parameter variation results in a significant decrease in efficiency, up to 84% for width changes compared to the ideal scenario. In particular, a change in leaf width affects efficiency more negatively than a change in a finish color, suggesting the need to minimize variation in this area during production planning. A drawback of the above simulation is assuming an unchanging, continuous situation over 8 hours. In practice, continuously producing one assortment for customized production is impossible. To actualize these forecasts, the situation of sorting door leaves by pallets, with e= 20 pieces each, was assumed. On each pallet, the elements would be identical to each other. Between successive pallets, the technological line settings would be adjusted. To simulate the worst-case scenario, it was assumed that between successive pallets, the line settings must be adjusted to changes in the width of the door leaves. Therefore, the time between the exit of the last element from the pallet and the exit of the first element from the subsequent pallet was assumed to be the highest average takt time from Fig. 2-4, which is $\overline{x_{us}}$= 64.21 seconds. The interval time for the subsequent products for door leaves from one pallet is the takt time for a sorted series which is $\overline{x_s}$= 10.06 seconds. The calculations were performed using the formula (3). Additionally, Figure 5 demonstrates that classification of door leaves, even in smaller sequences of 20 pieces, has a significant impact on the efficiency of the technological line. During an 8-hour workday, production planned in this manner is capable of processing 863 door pieces, resulting in 2589 completed machining cycles. This provides undeniable evidence of how crucial the sequence of processing products is. It also becomes apparent which of the examined features are most significant for line efficiency and which parameters should be prioritized first. The results can be used to determine the optimal processing sequence to reduce the number of necessary changes to the technological line setup.

Results from this study align with the conclusions found in the literature. The lower the variability in production, the shorter the cycle time, whereas any diversity significantly extends it or reduces efficiency (Barański *et al.*, 2017; Ehteshami *et al.*, 1992). Reducing cycle time is critical in production development (Zhang and Tag, 2006), particularly in highly advanced technical industries (Sherman *et al.*, 2000). It is an indicator closely related to resource utilization (Aurand and Miller, n.d.), making it a key challenge across many sectors (Kalir, 2023), as it directly affects production costs and enterprise revenues (Weber and Fayed, 2010). In addition, the differences in the number of manufactured door leaves indicate that implementing a strategy to group them according to the lowest possible variability of their parameters may be key to improving efficiency (Pędzik *et al.*, 2020).

CONCLUSION

Three characteristics of door leaves and their impact on the efficiency of the TechnoPORTA line are characterised in the study. The study revealed that the efficiency of the production line is significantly affected by the deliberate selection of the processing sequence for door leaves. All three discussed parameters should be considered to minimize takt time as much as possible. Width and the presence of a rebate or non-rebate were the most significant factors examined. With each change in these properties, the takt time increases sixfold compared to a series with no changes. Efficiency is reduced by half by adjusting the finish colour. When selecting the processing sequence, paying attention to these characteristics can increase efficiency several times, depending on the batch size with the same parameters. Without changes in the technological process, investments in new machinery, or compromising quality, efficiency can be significantly increased solely through the reorganization of one production stage. In the future, tests should be extended with parameters such as the height of the door leaf or the type of material used in production to determine each feature's relevance level.

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