

Article

The Efficiency of Edge Banding Module in a Mass Customized Line for Wooden Doors Production

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Abstract: The TechnoPORTA technology line is a fully automated smart line ensuring the highest quality and efficiency of production wooden doors. The aim of the study was to experimentally determine the performance of the edge banding module in the TechnoPORTA line on particular working days and to determine the possible influence of organizational and technological factors characterizing the line's operation, which can be defined and determined by analyzing the temporal technological data obtained from the IT systems controlling the line's operation. The research was conducted on the edge banding module, which is crucial to the performance of the entire TechnoPORTA line. During the study, data on door leaf machining were collected such as the mean time of production per one working cycle, mean time of retooling, number of retooling, number of door leaves leaving in a series, and most frequent time of series. The data collected by the IT system controlling the line indicates that this module is flexible and its performance is not related to the control parameters. The results can be used to improve the operation of the module and the replication of the work schedule to subsequent modules of the technological line.

Keywords: door industry; TechnoPORTA line; technological line; sustainable business model; IT systems



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1. Introduction

Davis [1], the creator of the concept of mass customization (MC), defined it as reaching a large number of customers, as is the case in mass markets, but also treating them individually, as in individualized markets. The assumption of MC is high individualization while maintaining relatively low costs and mass production efficiency [2]. Today, the term MC is used for strategies connected with high variety, personalization, and flexible production [3]. This results from the acceptance of the individual treatment of consumers. MC is also related to the increased global competition, shortening the life cycle of products as well as implementing new production and information technologies that enable companies to produce to customer specifications at low cost [4,5]. Facing the customer-driven market, the product design must cover a larger scope of the value chain and accentuate high-added value to the customers [6]. MC can be treated as a key instrument in building relations between producers and customers and gives manufacturers the opportunity to increase customer satisfaction, and hence customer retention in the long-term [7], which is followed by increasing customer loyalty [8].

According to the concept, mass personalization enables companies to achieve a competitive advantage through a product differentiation strategy while maintaining cost-effectiveness. Cavusoglu et al. [5] explained that if the customization cost is not low enough, companies should consider offering custom products instead of one single product. The authors emphasize that introducing flexibility requires a significant initial investment, known as the cost of operational flexibility. Furthermore, the mass production of tailor-made products cannot proceed directly without some loss of efficiency. Even in an increasingly individualized economy, many products are actually more semi-classic than completely custom-made. An example is a product in which the consumer can choose the species of wood, and the finish to be used in a particular design. Manufacturers of ready-to-assemble furniture are experiencing increasing demand from customers who expect products to be tailored to their specific needs such as a system for designing personalized ergonomic furniture (chairs, beds, tables, kitchen interiors, etc.) using anthropometric dimensions or other specific needs [9–12]. Based on the empirical test, Blecker and Abdelkafi [13] underlined that proliferation had a significant impact on cost due to the complexity of production, which affects the level of overhead costs. Of great importance, in addition to the variety of products, is the construction of the material being processed such as solid wood or wood-based panels, since the processing of wood-based materials is specific, which can sometimes limit the scope of customization [14,15]. As product variety increases, the planning complexity increases with more on-floor alternative routes, more work-in-progress inventory, assembly line balancing problems, increasing variability, etc. [13]. In the door industry, constraints on carrying out mass customization also arise from technical standards specifying requirements, for example, in terms of strength, intrusion resistance, soundproofing or other factors, with a particular focus on doors for public buildings [4].

Innovations in manufacturing processes should affect the cost reduction for the customer, reducing waste without additional resource requirements. Referring to the idea of a sustainable, circular economy, regeneration and the reuse of waste products and production residues can significantly reduce energy consumption and waste [16–18]. In modern production lines, achieving green production by saving energy and reducing emissions is possible by combining the automation of most production operations and the source and type of raw materials used in products such as using equally valuable forest biomass and its own production waste [16,19,20]. The answer to these requirements is lean manufacturing (LM) [21,22]. For any manufacturing company, machine breakdowns and downtime are a source of unavoidable costs. It is their reliability that affects the productivity of the company and directly affects the company's bottom line. More and more companies are recognizing the need to control the efficiency of machinery utilization, which allows them to identify waste in the technological processes implemented and the existing production reserves [23]. The target state that all enterprises should strive for is 100% utilization of the machinery park in their possession, and at the same time, no shortage of production is realized with an efficiency corresponding to the nominal efficiency of the technological equipment and machinery in their possession [24]. Based on these assumptions, the Porta KMI Poland door manufacturing plant is betting on innovation in the development and modernization of the production hall by creating a new customized TechnoPORTA technological line [25]. This is a fully automated intelligent module line that ensures the highest quality and production efficiency. Designed for mass customization while maintaining the required minimum production batch size (one door leaf), the line meets the highest technical requirements [4]. The line was developed using technologically advanced machinery and equipment, enabling the greatest possible automation of work at each stage of processing including the positioning and feeding of material and machine changeover [26,27].

The need for improvement in companies has existed for a long time, but in today's rapidly changing market, characterized by high dynamics and the need to flexibly adapt production to the needs, it is becoming essential to implement [28–31]. There are many tools and indicators for this to analyze the possibility of improving production processes in a manufacturing plant including TQM (total quality management) [32–34], lean manage-

ment [35,36], Six Sigma [37,38], and quality management system (QMS) in accordance with the ISO standards [39,40]. An essential support for process improvement is the provision of adequate human resources to effectively manage and improve processes [41,42]. Achieving a high level of product quality requires continuous monitoring, analysis, and improvement of the process. Continuous monitoring of the production process involves recording and collecting accurate data on its progress. This type of activity is an important part of a company's management strategy [43]. For this purpose, it is possible to use manual methods (i.e., filling out the appropriate index cards or forms), but especially electronic methods (i.e., using MES—manufacturing execution systems). However, in order to analyze the process, it can be difficult to coordinate the use of measurements with different specifications and simultaneously from multiple workstations. It is much more practical to use numerical indicators of a synthetic nature that combine data from different sources. For this purpose, so-called key performance indicators (KPIs) are used in manufacturing systems. KPIs are defined as a set of measures (metrics) used to facilitate the evaluation of the performance of a production system from the perspective of productivity, quality, and maintenance [44,45].

In light of the need to evaluate the use of modules in the TechnoPORTA line in order to determine the fulfilment of the productivity design assumptions under the conditions specified by the MC concept, it was decided to conduct research to obtain production data from the IT system controlling the operation of the line. The aim of this research was to experimentally determine the performance of the edge banding module in the TechnoPORTA line on particular working days and to determine the possible influence of organizational and technological factors characterizing the line's operation, which can be defined and determined by analyzing the temporal technological data obtained from the IT system controlling the line's operation.

2. Materials and Methods

The edge banding module, which is crucial to the performance of the entire TechnoPORTA line was selected for testing. During the production process, each door leaf passes through this module at least three times (up to six times) to process three edges (two sides and one top). Therefore in order to produce one door leaf, the module must perform from three to six working cycles. In this process, subsequent machining units perform the following actions:

1. Feeding door leaves for production (feeding portal);
2. Reference edge milling (reference milling machine);
3. Edge processing (the edge with a rebate processing machine);
4. Stacking and transfer to the further processing of door leaves (two-way stacking portal).

The arrangement diagram and the most important machine units are shown in Figures 1 and 2.

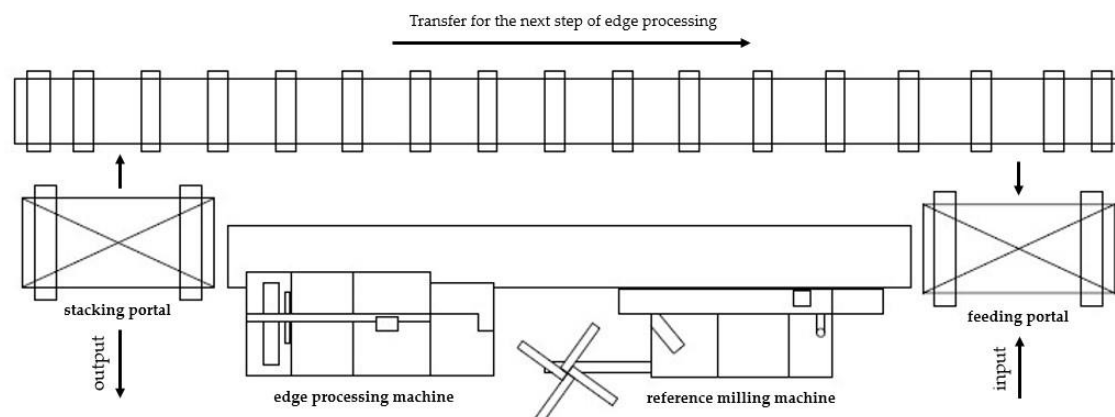


Figure 1. The arrangement diagram and the most important machine units of the edge banding module.



Figure 2. The units of the edge banding module: (A) feeding portal, (B) reference milling machine, (C) edge processing machine, (D) two-way stacking portal.

The research process consisted of two stages. In the first stage, machining data were collected from 14 September to 5 December 2020. Then, the data obtained from the IT system controlling the operation of the line were in the form of *.csv files. These data were analyzed in MS Excel software to determine the efficiency of the edge banding module.

A sample layout of machine data in a *.csv file is shown in Figure 3.

First, the data were sorted based on the “CYCLE” column (Figure 4). When the value in the column changed from “1” to “3”, for example, it means that an entire pallet of one type of door leaf has gone through the machine tools to machine one edge, and then the machines are retooled to another type of door leaves ready on the next pallet.

Using the “IF(C1 <> C2; 1; 0)” function, the data from the “CYCLE” column can be used to determine the moment when the machine retooling occurs. Passing through the first door leaf after retooling, it is marked with the number 1 in the “L” column. Then, in the “M” column, based on the “L” column, each series of processed door leaves is sequentially numbered thanks to the formula “=L2 + M1”.

	A	B	C	D	E	F	G	H	I	J	K
1	ID	Production_Barcode_ID	CYCLE	maxCYCLE	Status	Date	User	Date	Time	Tact	Retooling time
2	200394	123065054	2	3	10	2020-09-14 08:40:10.05	JB	14.09.2020	8:40:10	0:01:25	#NAME?
3	200395	123065055	2	3	10	2020-09-14 08:41:35.75	JB	14.09.2020	8:41:35	0:01:19	#NAME?
4	200396	123065056	2	3	10	2020-09-14 08:42:54.253	JB	14.09.2020	8:42:54	0:00:11	#NAME?
5	200397	123065057	2	3	10	2020-09-14 08:43:05.0	JB	14.09.2020	8:43:05	0:01:30	#NAME?
6	200398	123065059	2	3	10	2020-09-14 08:44:35.897	JB	14.09.2020	8:44:35	0:00:11	#NAME?
7	200399	123065060	2	3	10	2020-09-14 08:44:46.05	JB	14.09.2020	8:44:46	0:00:10	#NAME?
8	200400	123065061	2	3	10	2020-09-14 08:44:56.553	JB	14.09.2020	8:44:56	0:20:32	0:20:32
9	200401	123065062	2	3	10	2020-09-14 09:05:28.21	JB	14.09.2020	9:05:28	0:07:51	0:07:51
10	200402	123065063	2	3	10	2020-09-14 09:13:19.41	JB	14.09.2020	9:13:19	0:01:12	#NAME?
11	200403	1230650636	2	3	10	2020-09-14 09:14:31.493	JB	14.09.2020	9:14:31	0:01:36	#NAME?
12	200404	123065037	2	3	10	2020-09-14 09:16:07.557	JB	14.09.2020	9:16:07	0:00:10	#NAME?
13	200405	123065038	2	3	10	2020-09-14 09:16:17.75	JB	14.09.2020	9:16:17	0:00:11	#NAME?
14	200406	123065039	2	3	10	2020-09-14 09:16:28.207	JB	14.09.2020	9:16:28	0:02:34	#NAME?
15	200407	123065040	2	3	10	2020-09-14 09:19:02.607	JB	14.09.2020	9:19:02	0:00:36	#NAME?
16	200408	123065048	2	3	10	2020-09-14 09:19:38.497	JB	14.09.2020	9:19:38	0:00:09	#NAME?
17	200409	123065049	2	3	10	2020-09-14 09:19:47.943	JB	14.09.2020	9:19:47	0:01:17	#NAME?
18	200410	123065050	2	3	10	2020-09-14 09:21:04.95	JB	14.09.2020	9:21:04	0:00:11	#NAME?
19	200411	123065051	2	3	10	2020-09-14 09:21:15.053	JB	14.09.2020	9:21:15	0:00:10	#NAME?
20	200412	123065052	2	3	10	2020-09-14 09:21:25.35	JB	14.09.2020	9:21:25	0:00:16	#NAME?
21	200413	123065053	2	3	10	2020-09-14 09:21:41.95	JB	14.09.2020	9:21:41	0:00:11	#NAME?
22	200414	123065054	2	3	10	2020-09-14 09:21:52.25	JB	14.09.2020	9:21:52	0:00:10	#NAME?
23	200415	123065055	2	3	10	2020-09-14 09:22:02.2	JB	14.09.2020	9:22:02	0:00:10	#NAME?
24	200416	123065056	2	3	10	2020-09-14 09:22:12.957	JB	14.09.2020	9:22:12	0:02:08	#NAME?
25	200417	123065057	2	3	10	2020-09-14 09:24:20.403	JB	14.09.2020	9:24:20	0:00:12	#NAME?
26	200418	123065041	2	3	10	2020-09-14 09:24:32.603	JB	14.09.2020	9:24:32	0:00:10	#NAME?
27	200419	123065042	2	3	10	2020-09-14 09:24:42.557	JB	14.09.2020	9:24:42	0:00:11	#NAME?
28	200420	123065043	2	3	10	2020-09-14 09:24:53.153	JB	14.09.2020	9:24:53	0:00:10	#NAME?
29	200421	123065044	2	3	10	2020-09-14 09:25:03.16	JB	14.09.2020	9:25:03	0:00:10	#NAME?
30	200422	123065045	2	3	10	2020-09-14 09:25:13.5	JB	14.09.2020	9:25:13	0:00:49	#NAME?
31	200423	123065028	2	3	10	2020-09-14 09:26:02.85	JB	14.09.2020	9:26:02	0:00:11	#NAME?
32	200424	123065029	2	3	10	2020-09-14 09:26:13.35	JB	14.09.2020	9:26:13	0:00:10	#NAME?
33	200425	123065030	2	3	10	2020-09-14 09:26:23.1	JB	14.09.2020	9:26:23	0:00:10	#NAME?
34	200426	123065031	2	3	10	2020-09-14 09:26:33.497	JB	14.09.2020	9:26:33	0:00:10	#NAME?
35	200427	123065032	2	3	10	2020-09-14 09:26:43.843	JB	14.09.2020	9:26:43	0:00:18	#NAME?
36	200428	123065082	2	3	10	2020-09-14 09:27:01.197	JB	14.09.2020	9:27:01	0:00:10	#NAME?
37	200429	123065083	2	3	10	2020-09-14 09:27:11.397	JB	14.09.2020	9:27:11	0:00:10	#NAME?
38	200430	123065084	2	3	10	2020-09-14 09:27:21.2	JB	14.09.2020	9:27:21	0:00:10	#NAME?
39	200431	123065085	2	3	10	2020-09-14 09:27:31.593	JB	14.09.2020	9:27:31	0:00:10	#NAME?
40	200432	123065086	2	3	10	2020-09-14 09:27:41.543	JB	14.09.2020	9:27:41	0:00:10	#NAME?

Figure 3. An example of the machine report.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	ID	Production_Barcode_ID	CYCLE	maxCYCLE	Status	Date	User	Date	Time	Tact	Retooling time					Retooling y/n	Key	Max. Tact	Count
2	26827	123093324	2	6	10	2020-10-19 13:24:54.54	JB	19.10.2020	13:24:54	0:09:09	#NAME?	1	1	1	1	1	1y	0:09:09	1
3	26828	123357016	1	3	10	2020-10-19 13:34:03.303	JB	19.10.2020	13:34:03	0:00:12	#NAME?	1	2	5	5	0	2y	0:00:12	0
4	26829	123357015	1	3	10	2020-10-19 13:34:15.243	JB	19.10.2020	13:34:15	0:00:09	#NAME?	0	2	3	5	0			0
5	26830	123393375	1	3	10	2020-10-19 13:34:24.69	JB	19.10.2020	13:34:24	0:00:12	#NAME?	0	2	1	5	0			0
6	26831	123393376	1	3	10	2020-10-19 13:34:36.393	JB	19.10.2020	13:34:36	0:00:12	#NAME?	0	2	5	5	0	2y	0:00:12	0
7	26832	123393385	1	3	10	2020-10-19 13:34:48.337	JB	19.10.2020	13:34:48	0:01:03	#NAME?	0	2	1	5	0			0
8	26833	123225209	1	3	10	2020-10-19 13:35:51.39	JB	19.10.2020	13:35:51	0:00:12	#NAME?	0	2	5	5	0	2y	0:00:12	0
9	26834	123225208	1	3	10	2020-10-19 13:36:03.293	JB	19.10.2020	13:36:03	0:00:09	#NAME?	0	2	3	5	0			0
10	26835	123225203	1	3	10	2020-10-19 13:36:12.287	JB	19.10.2020	13:36:12	0:00:12	#NAME?	0	2	5	5	0	2y	0:00:12	0
11	26836	123225202	1	3	10	2020-10-19 13:36:24.297	JB	19.10.2020	13:36:24	0:00:09	#NAME?	0	2	3	5	0			0
12	26837	123225201	1	3	10	2020-10-19 13:36:33.287	JB	19.10.2020	13:36:33	0:00:12	#NAME?	0	2	5	5	0	2y	0:00:12	0
13	26838	123225200	1	3	10	2020-10-19 13:36:45.19	JB	19.10.2020	13:36:45	0:00:09	#NAME?	0	2	1	5	0			0
14	26839	123225199	1	3	10	2020-10-19 13:36:54.197	JB	19.10.2020	13:36:54	0:08:30	#NAME?	0	2			1 2y	0:08:30	1	
15	26840	123256303	3	6	10	2020-10-19 13:45:24.8	JB	19.10.2020	13:45:24	0:00:10	#NAME?	1	3	1	1	0	3y	0:00:10	0
16	26841	123256304	3	6	10	2020-10-19 13:45:34.94	JB	19.10.2020	13:45:34	0:00:11	#NAME?	0	3	1	1	0	3y	0:00:11	0
17	26842	123256305	3	6	10	2020-10-19 13:45:45.09	JB	19.10.2020	13:45:45	0:00:10	#NAME?	0	3	1	1	0	3y	0:00:10	0
18	26843	123256306	3	6	10	2020-10-19 13:45:55.25	JB	19.10.2020	13:45:55	0:01:57	#NAME?	0	3	1	1	0	3y	0:01:57	0
19	26844	123093324	3	6	10	2020-10-19 13:47:52.297	JB	19.10.2020	13:47:52	0:03:30	#NAME?	0	3			1 3y	0:03:30	2	
20	26845	123225199	2	3	10	2020-10-19 13:51:22.397	JB	19.10.2020	13:51:22	0:00:34	#NAME?	1	4	1	2	0			0
21	26846	123225200	2	3	10	2020-10-19 13:51:56.54	JB	19.10.2020	13:51:56	0:00:10	#NAME?	0	4	2	2	0	4y	0:00:10	0
22	26847	123225201	2	3	10	2020-10-19 13:52:06.537	JB	19.10.2020	13:52:06	0:00:10	#NAME?	0	4	1	2	0			0
23	26848	123225202	2	3	10	2020-10-19 13:52:16.543	JB	19.10.2020	13:52:16	0:00:10	#NAME?	0	4	2	2	0	4y	0:00:10	0
24	26849	123225203	2	3	10	2020-10-19 13:52:26.943	JB	19.10.2020	13:52:26	0:00:10	#NAME?	0	4	2	2	0	4y	0:00:10	0
25	26850	123225208	2	3	10	2020-10-19 13:52:36.893	JB	19.10.2020	13:52:36	0:00:11	#NAME?	0	4	1	2	0			0
26	26851	123225209	2	3	10	2020-10-19 13:52:47.09	JB	19.10.2020	13:52:47	0:03:39	#NAME?	0	4	1	2	0			0
27	26852	123393385	2	3	10	2020-10-19 13:56:26.55	JB	19.10.2020	13:56:26	0:00:10	#NAME?	0	4	2	2	0	4y	0:00:10	0
28	26853	123393376	2	3	10	2020-10-19 13:56:36.69	JB	19.10.2020	13:56:36	0:04:03	#NAME?	0	4	1	2	0			0
29	26854	123393375	2	3	10	2020-10-19 14:00:39.193	JB	19.10.2020	14:00:39	0:00:35	#NAME?	0	4	1	2	0			0
30	26855	123357015	2	3	10	2020-10-19 14:01:14.697	JB	19.10.2020	14:01:14	0:03:10	#NAME?	0	4	1	2	0			0
31	26856	123357016	2	3	10	2020-10-19 14:04:24.04	JB	19.10.2020	14:04:24	0:03:18	#NAME?	0	4			1 4y		0:03:18	0

Figure 4. An example of the machine data sorted by the column “CYCLE”.

Based on the obtained data in column F (Date), the start and end time of the work shift could be determined. Based on these times, the production time for each day of door leaves production was calculated. From column B (Production Barcode ID), it was possible to count the number of working cycles performed on the door leaves produced each production day. These two parameters are very important for the main parameter characterizing production (i.e., the number of cycles performed per minute).

Column J shows the times of a working cycle for the production of door leaves. From these data, it was possible to calculate the average production time per working cycle using the function “=AVERAGE(Jx;Jy)”. Using the function “=MODESINGL(Jx;Jy)” it was possible to find the most frequently occurring working cycle time, and using the function “=COUNTIF(Jx;Jy;most frequent time)”, we could count how many times this time was reached during production.

Column K shows the retooling time. Using the filter, it was possible to extract and display only those rows containing times when retooling occurred. From the data displayed in this way, it was possible to calculate the average time for retooling for individual production days “=AVERAGE(Kx;Ky)” and the number of retooling occurred “=COUNT(Kx;Ky)”.

All of these parameters (mean time of production per one working cycle, mean time of retooling, number of retooling, number of door leaves leaving in a series, most frequent time of series) were summarized in a sheet (Figure 5) and then processed in the form of graphs.

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
	Date	Start of production	End of production	Time of production	Convert to minutes	Number of doors on the pallet	Number of door leave	Number of cycles performed per min	Mean time of the cycle	Convert to seconds	Retooling time	Convert to minutes	Number of retoolings	Number of most frequent time	Convert to minutes	Most frequent time in %		
1	14.09.2020	8:40:10	13:47:31	5:07:21	307.35000	20.26667	265	0.86221	0:01:10	70.00000	0:17:08	17.12576	10	4	0.66667	0.21691		
2	15.09.2020	6:38:33	18:43:53	12:05:20	725.33333	40.66667	1017	1.40211	0:00:43	42.79253	0:15:06	15.10000	27	13	2.16667	0.29871		
3	16.09.2020	8:23:10	18:39:04	10:15:54	615.90000	32.40909	714	1.15928	0:00:52	51.75630	0:15:48	15.80079	20	13	2.16667	0.35179		
4	17.09.2020	8:18:55	18:46:52	10:27:57	627.95000	23.29730	863	1.37431	0:00:44	43.65817	0:15:19	15.31667	21	15	2.50000	0.39812		
5	18.09.2020	6:43:25	18:34:57	11:51:32	711.53333	22.67241	1286	1.80736	0:00:33	33.19751	0:10:52	10.86746	21	27	4.50000	0.63244		
6	19.09.2020	7:15:11	13:39:31	6:24:20	384.33333	40.50000	1003	2.60971	0:00:23	22.99103	0:11:47	11.78704	9	3	0.50000	0.13010		
7	21.09.2020	6:48:19	13:47:09	6:58:50	418.83333	14.16393	865	2.06526	0:00:29	29.05202	0:11:08	11.13030	11	30	5.00000	1.19379		
8	22.09.2020	6:44:31	12:32:00	5:47:29	347.48333	19.12500	919	2.64473	0:00:23	22.68662	0:08:39	8.65278	6	25	4.16667	1.19910		
9	23.09.2020	7:04:53	13:40:58	6:36:05	396.08333	35.84000	876	2.21166	0:00:27	27.12900	0:09:30	9.49861	12	12	2.00000	0.50494		
10	24.09.2020	6:43:16	13:52:48	7:09:32	429.53333	19.66667	1025	2.38631	0:00:25	25.14341	0:15:14	15.23095	7	33	5.50000	1.28046		
11	25.09.2020	8:10:27	20:58:18	12:47:51	767.85000	20.51282	801	1.04317	0:00:58	57.51685	0:11:43	11.71838	39	12	2.00000	0.26047		
12	28.09.2020	6:49:54	19:19:36	12:29:42	749.70000	22.68182	1498	1.99813	0:00:30	30.02804	0:13:35	13.58704	18	38	6.33333	0.84478		
13	29.09.2020	6:45:51	18:00:43	11:14:52	674.86667	31.41379	912	1.35138	0:00:44	44.39912	0:14:27	14.45287	29	8	1.33333	0.19757		
14	30.09.2020	6:47:11	21:04:13	14:17:02	857.03333	22.70588	1159	1.35234	0:00:44	44.36756	0:12:41	12.68542	32	29	4.83333	0.56396		
15	01.10.2020	7:08:45	13:51:09	6:42:24	402.40000	20.00000	541	1.34443	0:00:45	44.62847	0:16:15	16.24394	11	9	1.50000	0.37276		
16	02.10.2020	6:34:01	13:40:44	7:06:43	426.71667	19.61702	923	2.16303	0:00:28	27.73889	0:15:07	15.11042	8	26	4.33333	1.01551		
17	05.10.2020	6:38:47	13:51:13	7:12:26	432.43333	28.62500	628	1.45225	0:00:41	41.31529	0:22:36	22.59500	10	6	1.00000	0.23125		
18	06.10.2020	6:49:37	15:48:09	8:58:32	538.53333	18.87500	949	1.76219	0:00:34	34.04847	0:19:14	19.23889	12	20	3.33333	0.61897		
19	07.10.2020	7:22:10	15:45:41	8:23:31	503.51667	20.36585	854	1.69607	0:00:35	35.37588	0:10:55	10.91905	21	23	3.83333	0.76131		
20	08.10.2020	6:30:23	21:32:09	15:01:46	901.76667	17.20000	1807	2.00384	0:00:30	29.94245	0:10:39	10.65402	29	54	9.00000	0.99804		
21	09.10.2020	6:33:00	21:19:55	14:46:55	886.91667	15.73239	1118	1.26055	0:00:48	47.59839	0:22:05	22.08788	22	31	5.16667	0.58254		
22	12.10.2020	6:49:01	13:48:10	6:59:09	419.15000	46.52174	1071	2.55517	0:00:23	23.48179	0:13:06	13.10185	9	14	2.33333	0.55668		
23	13.10.2020	6:51:51	13:46:14	6:54:23	414.38333	18.80000	754	1.81957	0:00:33	32.97480	0:10:04	10.06458	16	8	1.33333	0.32176		
24	14.10.2020	6:56:47	16:19:51	9:23:04	563.06667	19.80769	1031	1.83104	0:00:33	32.76819	0:12:06	12.10526	19	15	2.50000	0.44400		
25	15.10.2020	6:49:41	21:10:39	14:20:58	860.96667	23.87143	1672	1.94200	0:00:31	30.89593	0:10:55	10.91905	21	14	2.33333	0.27101		
26	16.10.2020	7:03:12	17:13:48	10:10:36	610.60000	26.14815	1413	2.31412	0:00:26	25.92781	0:09:02	9.03148	18	22	3.66667	0.60050		
27	19.10.2020	6:58:32	21:26:37	14:28:05	868.08333	28.17647059	1438	1.656522991	0:00:36	36.22044506	0:13:05	13.08988	28	24	4	0.46078525		

Figure 5. An example of the statistical parameters determined based on the machine data.

At the end of the analysis, another sheet was created in the form of a contingency table, in which the calculated statistical parameters were averaged for each production day in the analyzed period (Figure 6).

Values					
Date	Average lowest time	Average highest time	Sum of number of door on pallet	Sum of time without retooling	
September 14, 2020	0:00:58	0:12:52	304	0:13:28	
September 15, 2020	0:00:17	0:11:50	976	0:38:01	
September 16, 2020	0:00:09	0:14:46	713	0:19:54	
September 17, 2020	0:00:20	0:08:22	862	0:20:52	
September 18, 2020	0:00:20	0:05:22	1315	0:42:02	
September 19, 2020	0:00:09	0:04:33	972	0:09:04	
September 21, 2020	0:00:22	0:02:39	918	0:13:38	
September 22, 2020	0:00:45	0:05:09	896	0:07:59	
September 23, 2020	0:00:16	0:03:34	1003	0:19:50	
September 24, 2020	0:00:41	0:08:30	800	0:36:29	
September 25, 2020	0:00:31	0:03:01	864	0:25:33	
September 28, 2020	0:00:37	0:05:19	1497	0:36:22	
September 29, 2020	0:00:15	0:12:33	911	0:37:54	
September 30, 2020	0:00:27	0:08:21	1158	1:11:23	
SUM	0:00:26	0:06:36	13189	6:32:29	

Figure 6. An example of the monthly averaged data.

The results were summarized within the months of the study period (broken down into data from September, October, November, and December).

3. Results

The number of working cycles per shift in the function of the mean time of the cycle shows the strict theoretical inversely proportional relationship (Figure 7). However, this was not the subject of this analysis. It is important to show that under favorable conditions,

the edge banding module of the TechnoPORTA line could achieve an efficiency level of over 2.5 cycles per minute. However, it is often lower, sometimes only 0.5 cycles per minute. This means that there are factors that limit this performance. The scientific goal should be to identify these factors and the business goal to eliminate or reduce their impact.

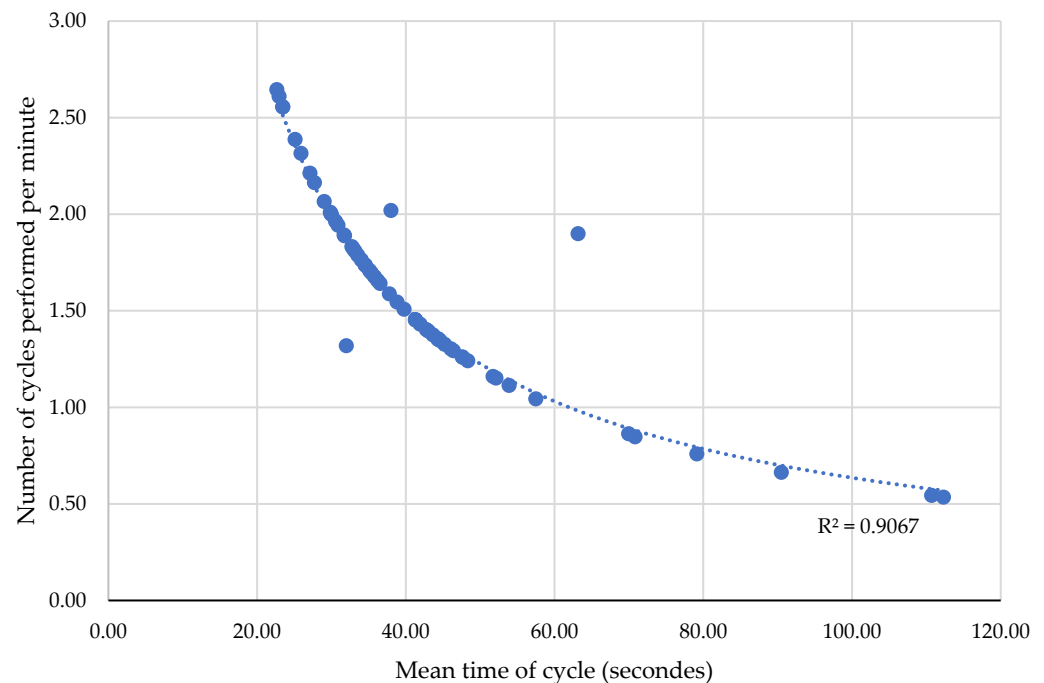


Figure 7. Dependence of the number of cycle doors per minute on the mean time of the cycle.

Figures 8–11 show that there is a low level of influence of internal factors, which can be determined based on the production data on the efficiency of this module. Figure 8 shows that the average mean time of retooling is between 10 and 20 min. The number of cycles performed per minute is not dependent on the average mean time of retooling. The number of retoolings from 5 to more than 40 did not change the number of cycles performed per minute, falling within the range of 0.5 to 2.5 per minute (Figure 9). Similarly, the number of doors per pallet, ranging from 10 to even 60, did not affect the efficiency (Figure 10). The most frequent processing times per day fell within a wide range from 3 to 54 cycles. Their number is irrelevant to the performance calculated in cycles per minute (Figure 11). Although the overall efficiency range was between 0.5 and 2.5 cycles per minute, on the vast majority of days, a narrower range of 1 to 2 cycles per minute was achieved, regardless of the values of the internal factors measured.

The mean time of retooling, number of retooling, number of doors on the pallet, and number of the most frequent time in one working shift did not influence the efficiency of the customized module of the edge banding of door leaves. It can be concluded that the machine data collected from 14 September to 5 December 2020 did not allow us to identify factors influencing the daily variability of efficiency. Either the IT system was unable to catch them in this time, or they were outside the area controlled by the system.

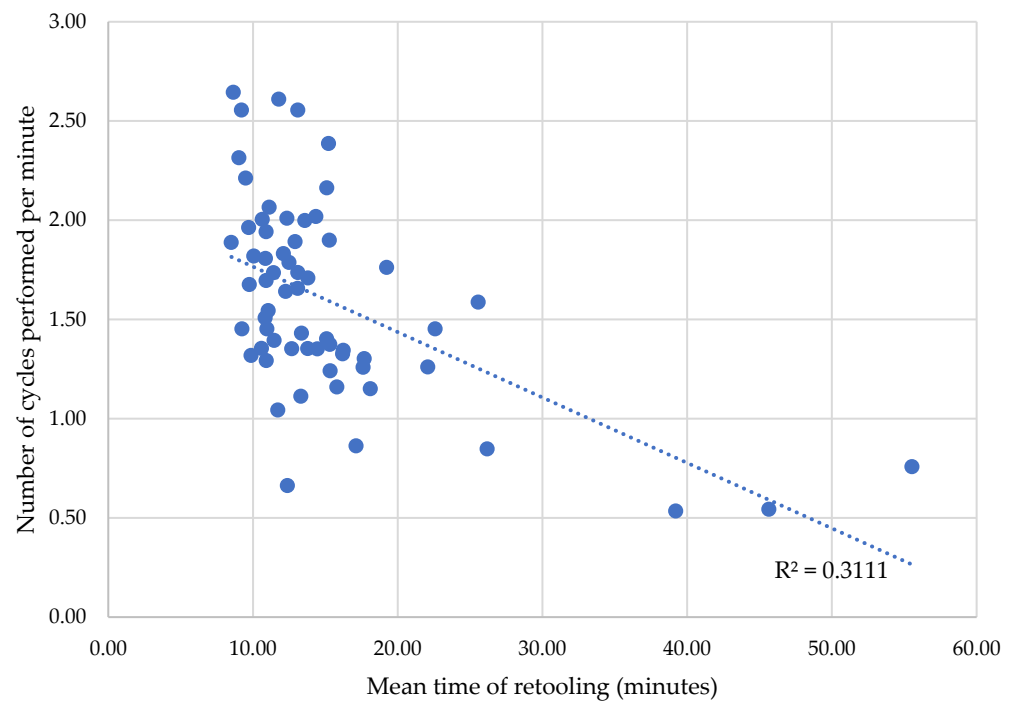


Figure 8. Dependence of the number of cycles performed per minute on the mean time of retooling.

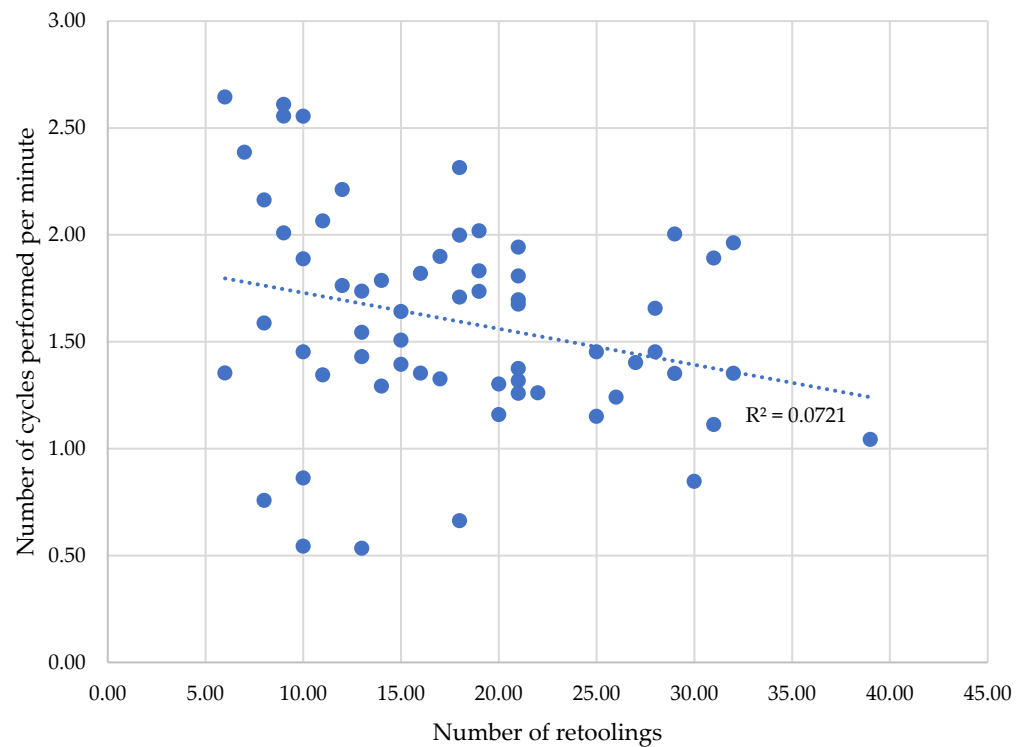


Figure 9. Dependence of the number of cycles performed per minute on the number of retoolings.

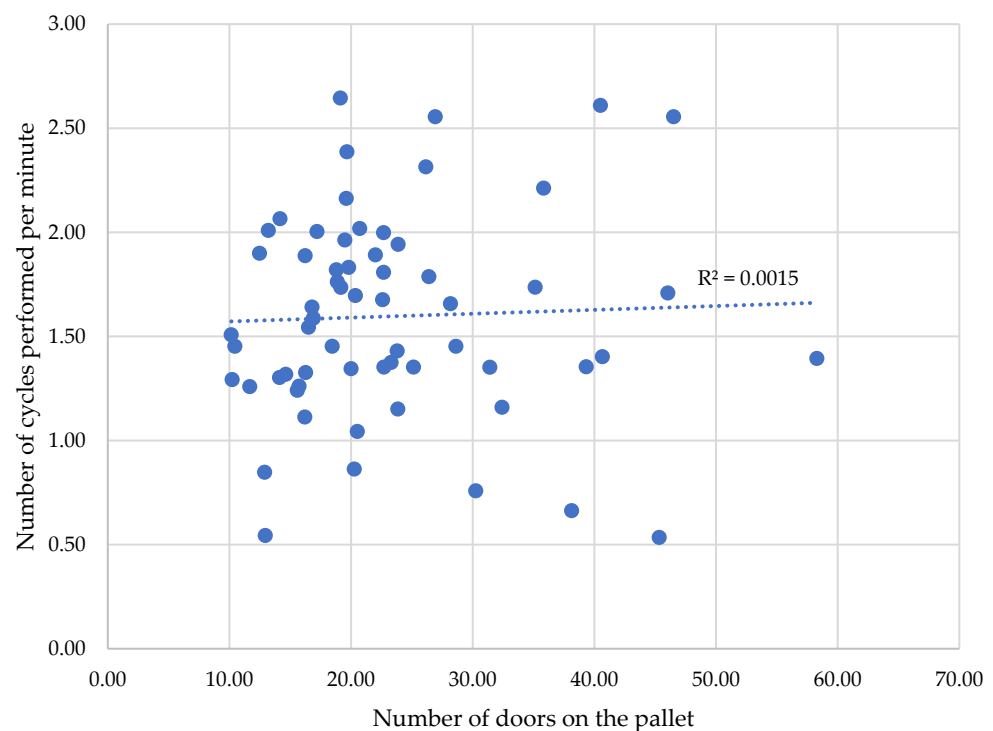


Figure 10. Dependence of the number of cycles performed per minute on the number of doors on the pallet.

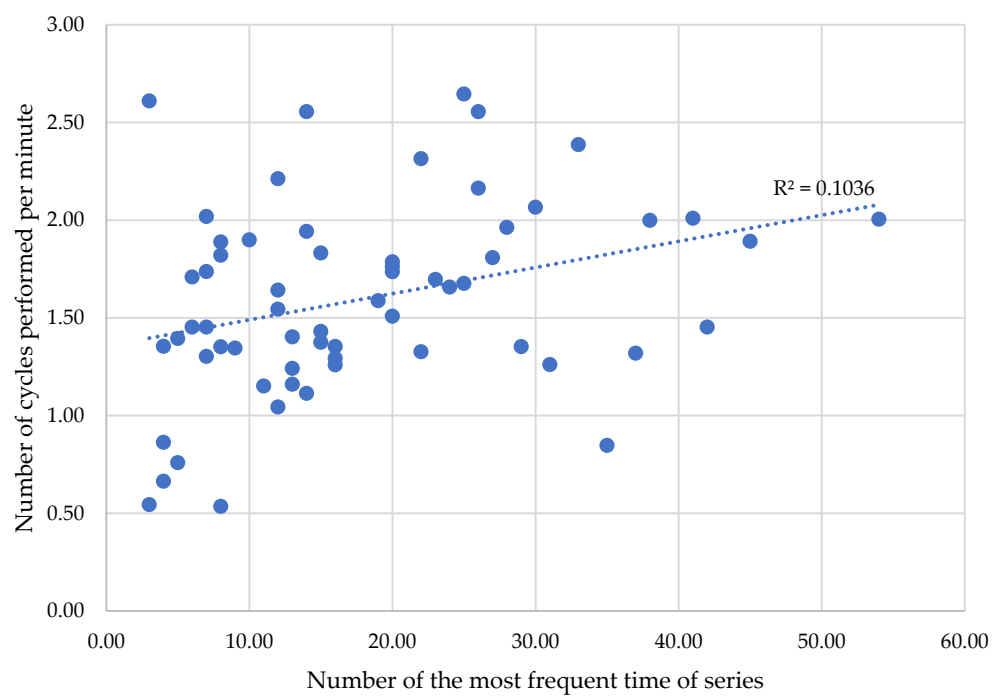


Figure 11. Dependence of the number of cycles performed per minute and the number of the most frequent time of series.

4. Discussion

Although MC is a trend that nowadays is developing dynamically, companies can perceive this phenomenon as a significant challenge. It happens because it requires both the products and the production processes to be customized [46].

There are two basic groups of limitations of mass customization connected with external (customer, market) and internal (production, logistic) elements, looking from the point of view of entities [47]. The first group of restrictions associated with external factors are related to the structure of the market and unfavorable demand conditions. It is fundamental for companies to determine whether there is a potential market demand big enough to respond to the customers' preferences and expectations. It is mostly connected with visible and measurable demand conditions that appear on the market. Customers demand variety when they differ sharply in their preferences for certain attributes of a product. Under such circumstances, customization may truly add value [5,47]. Production processes must be flexible to provide individual product features, bearing in mind the impact of the technological and material parameters on the final quality of, for example, the final processing surface during edge banding, milling, or other operations in individual technological line modules [48,49]. Milling is at the forefront of operations with which to give the final product the characteristics the customer wants. On the other hand, any slowdown or recession may reduce the rationality of the implementation of the customization process.

It is also worth noting that the changes on the market have a cyclical nature (the theory of business cycles). In particular, the concept of Kitchin's minor business cycle can be applied. described by Grasselli and Nguyen-Huu [50], taking a supply-side perspective, manufacturers decide on the level of production based on the expected level of demand and the desired level of inventory. On the demand side, investment is determined as a function of utilization and profitability and can be financed by debt, whereas consumption is independently determined as a function of income and wealth. In business activities, the time lags in information and decision adjustment affect the prices, output, demand, inventory, and employment in a periodic manner [50].

Mendelson and Parlaktürk [51] found that the implementation of MC depends on the company's competitive position on the market. They concluded that in a competitive environment, before introducing MC, a company should consider reducing costs or making efforts to improve the product quality. In the case of a monopoly, where price competition does not exist, the company can easily implement costless personalization. However, strong competition in the market makes companies accept worse financial results than if they offered standard products [5].

The internal adverse factors of companies are those connected with production, technologies, and logistics. Mass customization requires a highly flexible production technology [4]. Increasing flexibility takes place through the implemented innovations in the field of modular structures and cost-effective operations as well as the increasingly common use of information and digital technology to control production devices. Product-process-supply chain engineering is coexistent in MC. Manufacturers implement reconfigurable production systems (RMS) that help to operate in unpredictable and changeable markets through the machines' reconfigurability and flexibility [2]. Nevertheless, as described by Modrak and Soltysova [52], assembly line balancing causes difficult and important problems for manufacturers. Mass customization also requires a properly adapted logistics system for the customer [47].

Taking into account the above-mentioned external and internal factors, companies have to decide not only on whether to customize their products to the needs of the consumers, but also the level of this adaptation. As mentioned by Hou et al. [53], manufacturers can use optimization models to balance the costs of customization and the economies of the scale of mass production. In industry, only certain product features can be customized because only certain processing steps are sufficiently flexible.

The results of the study showed that neither the mean time of retooling, the number of retooling a working shift, the number of door leaves on the pallet, nor the number of the most frequent processing time in a door leaves series influenced the efficiency of the line. These technological and production organization parameters are the internal factors of the line, which can be calculated based on the machine reports generated and recorded

in the IT production system. Therefore, it can be said that the edge banding module in the TechnoPORTA line is flexible in known and measurable conditions.

However, as a result of the tests, a significant variation in the line efficiency was found, defined by the average number of door leaves produced per minute, which was from just over 0.5 to over 2.5 pieces per minute. This proves the presence of external factors influencing the efficiency of the line, which could be connected with the customers' order structure or internal factors unidentified in the conducted tests. In this case, external factors may include the volatility of the structure characteristic of the customers' orders. On the other hand, the IT production control system was updated and reprogrammed to identify possible internal factors related to the operation of the TechnoPORTA line. The efficiency of the line was also further stabilized, but it is still necessary to carry out more extended working time observations, especially in terms of identifying the causes of downtime.

5. Conclusions

Based on the analysis of the obtained data and the discussion on the factors limiting mass customized production systems, it can be concluded that in the case of the edge banding module of the TechnoPORTA line, there was no influence of the mean time of retooling, the number of retooling, the number of doors on the pallet, and the number of the most frequent time in one working shift on the efficiency of this module. The data collected by the IT system controlling the line indicates that this module is flexible and its performance is not related to the control parameters. However, the large differences in efficiency on individual days indicate the existence of efficiency-limiting factors. Therefore, for the effective implementation of mass customization, thanks to which the efficiency of the line modules will be stable and their operation as flexible as possible, it is necessary to conduct planned technological tests to identify these factors and their significance. In order to identify them, the process engineering department reprogrammed the IT system to use production scheduling (ERP) data. Tests are in progress, which will show that the identification and control of the technological factors improve the performance of the customized line. The further direction of research will be the interpretation of the results obtained, and based on them, the determination of further work to improve the operation of the module and the replication of the work schedule to subsequent modules of the technological line.

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