TiAM kwartalnik naukowo-techniczny
TECHNOLOGIA I AUTOMATYZACJA MONTAŻU
ZESPOŁÓW • MASZYN • URZĄDZEŃ

Magdalena Dąbrowska[1], Katarzyna Maciejewska[2]

DOI: 10.7862/tiam.2022.2.3

OPTIMISING THE SEALING STATION IN PRODUCTION PROCESS OF TUBES FOR CATALYTIC CONVERTERS INVOLVING SMED METHOD – A CASE STUDY

OPTYMALIZACJA STANOWISKA USZCZELNIANIA W PROCESIE PRODUKCYJNYM PRZEWODÓW DO KATALIZATORÓW Z WYKORZYSTANIEM METODY SMED – STUDIUM PRZYPADKU

Abstract

The article presents the stages of the development of the lean management concept. The authors presented the SMED methodology. They made the analysis of the sealing station in the production process of tubes for catalytic converters in relation to the real model. Optimisation the sealing station in production process of tubes for catalytic converters has been done in this article. For this purpose was used one of the tools of Lean Manufacturing, SMED. Diagnosis of machine changeover operations was carried out and also measurement of the times necessary for doing these operations. Using spaghetti diagram, the path which is covered by the operator during machine changeover, was shown. Delegation of specific tasks carried out previously by the operator to production workers and implementation of organisational and technical solution has had the effect of relieving of the operator and shortening of time necessary for machine changeover and increasing productivity at the sealing station .

Keywords: lean management, SMED, optimisation, production process, spaghetti diagram

Streszczenie

W artykule przedstawiono etapy rozwoju koncepcji lean management. Autorki zaprezentowały metodologię SMED. Dokonały analizy stanowiska uszczelniania w procesie produkcyjnym przewodów do katalizatorów w odniesieniu do modelu rzeczywistego. W artykule dokonano optymalizacji stanowiska uszczelniania w procesie produkcyjnym przewodów do katalizatorów. W tym celu zastosowano jedno z narzędzi Lean Production, a mianowicie SMED. Dokonano diagnozy czynności wykonywanych podczas przezbrajania maszyny oraz dokonano pomiaru czasów niezbędnych do wykonania wskazanych czynności. Wykorzystując diagram spaghetti zilustrowano drogę, którą pokonuje operator podczas przezbrojenia maszyny. Oddelegowanie wybranych czynności wykonywanych uprzednio przez operatora na obsługę produkcji oraz wprowadzenie rozwiązania organizacyjno-technicznego wpłynęło na odciążenie operatora i skrócenie czasu niezbędnego do przezbrojenia maszyny i zwiększenia produktywności na stanowisku uszczelniania.

Słowa kluczowe: lean management, SMED, optymalizacja, proces produkcyjny, diagram spaghetti

1. Introduction

There are many definitions of Lean Management and Lean Production in the literature. In the light of the selected definitions the conception of Lean Management is perceived as strategy, with regard to others as philosophy, and still others as a method [1], [3], [4], [6], [10], [12], [13], [18], [20]. For the first time the concept of Lean Production was used in 1988 and was used for the purpose of showing the difference between classic mass production system (traditional management) and management based on pillars of Toyota Production System – TPS (lean management) [5]. The evolution of Toyota production system started in 1948 from implementation of suction system at the engine department. There was implemented the order to reverse to the previous operational position in order

[1] PhD, Magdalena Dąbrowska, Collegium Witelona State University, Faculty of Technical and Economic Sciences, Department of Production Engineering and Logistics, Sejmowa Street 5A, 59-220 Legnica, Poland, e-mail: magdalena.dabrowska@collegiumwitelona.pl, ORCID: 0000-0002-9305-7123.

[2] Eng. Katarzyna Maciejewska, Collegium Witelona State University, Faculty of Technical and Economic Sciences, Research Club on Logistics and Transport.

to take inventory parts necessary for production. The aim of the action was to eliminate interim stocks by in-depth stock control which was dictated by losses due to inflation and lack of armaments procurement. The suction system was applied at the processing department in 1949. Due to low demand from the market, all machines were not fully loaded and hence one employee had to operate several machines at the same time. In 1950 the decision about the extension of the concept of pull system on marketing activities, synchronisation of departments and introduction of traffic lights was undertaken. The undertaken decision about synchronisation of engine machining and gearboxes with department of final assembly had an impact on further reduction of interim stocks. The introduction of traffic lights on selected production lines contributed to shortening the notification time to the supervisiory services about occurring problems. In 1953 kanban system was implemented (more on kanban system see [9], [11]). In order to simplify production, purchase and transportation processes, there was implemented standardisation of parts and components in the enterprise. In 1955 Toyota introduced solutions giving possibility of further reduction of stocks through line delivery control systems, it also started balancing production (both in terms of quantity and range) taking into consideration better use of machinery and equipment (more on heijunka technique see [2] [8]). In 1957 traffic lights were introduced on all production lines and four years later Toyota implemented kanban system to factories of selected suppliers. In 1962 existing kanban system was extended to all departments and production units. This approach enabled production according to pull principle with respect to small batches and on a company-wide basis. Additionally, error prevention system was introduced, its aim was to eliminate defects and prevent overproduction. Achieving economically viable production in small batches, more efficient use of machinery and equipment, reduction of stocks as well as reduction of production lead times were achieved by reduction of changeover times of many production machinery and plant. In 1963 labour productivity was increased. Employees started to handle five machines on average (comparing: up to 1947 they handled one machine, in 1947 – two machines, in 1949 – from three to four machines). Two years later kanban system was extended to external suppliers. In addition, practices for redeployment of assembly workers between different operational posts were introduced. In 1973 Toyota started to integrate suppliers with its internal parts flow system and thereby making it possible to deliver parts directly to the assembly line by their suppliers [7], [19].

According to reference literature, the most important tools in Lean Production are [17]: 5S, Kaizen, Just in Time, Kanban, SMED, TPM, VSM.

The aim of this article is optimisation of the sealing station in the production process of cables for catalytic converters based on the application of the SMED method. The optimization criteria are: reduction of the changeover time of machine, increasing productivity at sealing station, shortening the distance for the operator during changeover the machine.

2. SMED methodology

The aim of the method is changeover within a few minutes. Machines changeover is labour-intensive process which does not add value but is time-consuming. Application of SMED method allows for the reduction of changeover time [15]. The starting point for the application of this method is breakdown of changeover activities into internal operations and external operations. Internal operations are performed on a switched-off machine. However, it is important to remember that to the duration of this activity must be added start time, machine start-up time, time to reach full capacity. External operations are activities which can be done without shutting down the machine (can be done during machine operation). These are mostly preparatory activities aiming introduction of changes. Internal operations cause not only loss of working efficiency, but also reduce production time. Changeover time is time counted from the moment of making the last good item made for the "old order" to the production of the first good item of "new order". SMED methodology is based on four steps [14] [16]:

- step 0 – observation and recording of changeover process,
- step 1 – analysis of the collected materials and division of activities into internal and external changeover,
- step 2 – transformation of internal activities into external ones,
- step 3 – streamlining all aspects of changeover operations.

First step is to specify all changeover operations. Next, every operation must be described using status „internal operation" or "external operation" – according to the adopted definition. Then all operations are grouped. All external operations are included in group of external operations and all internal operations are included in the group of internal operations. Each activity has assigned duration. His way, sum of the times of „external operations" and sum of the times of "internal operations" are obtained. Internal operations should be divided taking into consideration possibility of their fulfilment in system of external operations. If there is such a possibility, they shall be given the new status of “external operations”. Other activities do not change their status. This results in a new distribution of operations, thus reducing sum of the times of internal operations.

3. Analysis of the sealing station in the production process of tubes for catalytic converters – real model

Size of production orders of tubes for catalytic converters is variable and varies from 50 items/order (this is minimum order size because of the changeover time and cost-efficiency) to 500 items/production order. Changeover on assembly station is always made by machine operators. It means that the more changeovers and their longer duration the more decreases machine capacity and hence – the whole production line.

The changeover procedure is based on 15 activities. Operator starts changeover from finishing previous order in MMS system and starting of the new order. The barcode, which is presented on the production order is scanned into the system by the use of a scanner. The system reads the order and displays to the operators all the necessary information: order and article number which will be produced, types of components which must be used in production and information about necessary equipment which should be used. The operator who has all information starts the changeover process. The operator using suitable keys (hex key) unscrews the handle that stabilises the position of the coupling during the sealing process. Handles vary depending on type of coupling used in order and use of incorrect handle may cause coupling failure. Equipment removed from the machine is put away on special stand and at the same time the handle necessary for production of next order is taken. Next, the operator starts dismanling so called dice and assembling the right dice which hold the cable on the machine in order to avoid its damage. They differ in diameter depending on type of protective hose used in production. When the correct equipment is fitted, the operator can adjust the program in the machine to indicated in production order. Next, the right length of belt on the dispenser is adjusted (in some cases it has to be changed). Next step is emptying of containers with sealing strips and taking bulk packaging to the supermarket and collection of bulk packaging with suitable sealing strips indicated in order from supermarket. Next step is to apply the right amount of strips to smaller containers located in the machine. The machine is converted and components which were placed in it, will be used in production. Then the operator completes job documentation and error sheet, these are documents which contain all information concerning the order. The documents are signed by the operator. Then the employee goes to the conduit container and takes the appropriate amount of conduits and starts their sealing (Table 1). The average total changeover time per machine is 16 min 39 sec. During one shift the amount of changeovers varies from 4 to 9, depending on the size of orders. Table 2 presents summary of changeover times per day and per week for minimal (1), average (4) and maximum number of changeovers (9). Table 3 presents summary of distances covered by operator during changeover per day and per week for minimal (1), average (4) and maximum number of changeovers (9). The cable sealing position is a socket. The machines are close to each other. Nearby there are storage rack for equipment necessary for changeovers and supermarket with components required in production. Figure 1 presents, with the help of spaghetti diagram, the path of moving of one operator during preparation of machines for the next order. The operations are numbered according to list of actions presented in Table 1. Other actions, which are not marked on the diagram, the operator carries out on site (they do not require mobility).

Table 1. List of operations and times during changeover before optimisation

Singular	Operation	Operation time (1 machine)	Operation time (3 machines)	Time (total)	Path [m]	Path (total)	Internal operation	External operation	Comments
1.	End of order in the system and start of a new order	00:02:06	00:02:06	00:02:06	2	2		X	One of operators finishes and starts order in system
2.	Dismantling of the handle that stabilises the position of coupling	00:00:56	00:02:48	00:04:54	2	4	X		
3.	Putting the equipment back in place	00:00:43	00:02:09	00:07:03	7,5	11,5		X	Operators have to move: butyl 1 - 3m, butyl 2 - 3m, butyl 3 - 1,5m

Table 1 (cont.). List of operations and times during changeover before optimisation

Sin-gular	Operation	Operation time (1 machine)	Operation time (3 machines)	Time (total)	Path [m]	Path (total)	Internal operation	External operation	Comments
4.	Finding and retrieving suitable equipment	00:03:19	00:09:57	00:17:00	7,5	19		X	Operators have to move: butyl 1 - 3m, butyl 2 - 3m, butyl 3 - 1,5m
5.	Connecting a new holder to stabilise the position of coupling	00:00:57	00:02:51	00:19:51	0	19	X		
6.	Dismantling and assembly of remaining dice	00:01:54	00:05:42	00:25:33	0	19	X		
7.	Setting the programme in the machine	00:00:34	00:01:42	00:27:15	0	19	X		
8.	Setting up the dispenser	00:00:18	00:00:54	00:28:09	0	19	X		
9.	Putting back the sealing strips from the containers into the bulk packaging	00:01:42	00:05:06	00:33:15	0	19		X	
10.	Putting back the bulk packaging to supermarket	00:00:26	00:00:26	00:33:41	3	22		X	One of the operators puts back component to the supermarket
11.	Pickup the appropriate bulk packaging from the supermarket	00:00:31	00:00:31	00:34:12	3	25		X	One of the operators picks up component from the supermarket
12.	Picking up sealing strips from bulk packaging to containers	00:01:07	00:03:21	00:37:33	0	25		X	
13.	Completing documentation and error sheet	00:00:53	00:02:39	00:40:12	0	25	X		
14.	Cable collection	00:00:07	00:00:21	00:40:33	4,5	29,5	X		The distance of the container with cables from each operator is 1,5m
15.	Production and inspection 1 item.	00:01:06	00:03:18	00:43:51	0	29,5	X		
	TOTAL	00:16:39	00:43:51	00:43:51	29,5	29,5	8	7	

Table 2. Changeover times per day and per week

Number of changeovers	Changeover time of 1 machine	Changeover time of 3 machines	Changeover time of 1 machine/ week	Changeover time of 3 machines / week
1	00:16:39	00:49:57	01:23:15	04:09:45
4	01:06:36	03:19:48	05:33:00	16:39:00
9	02:29:51	07:29:33	12:29:15	01:13:27:45

Table 3. List of distances during changeover per day and per week

Number of changeovers	path / 1 shift [m]	path / week [m]
1	29,5	147,5
4	118	590
9	265,5	1327,5

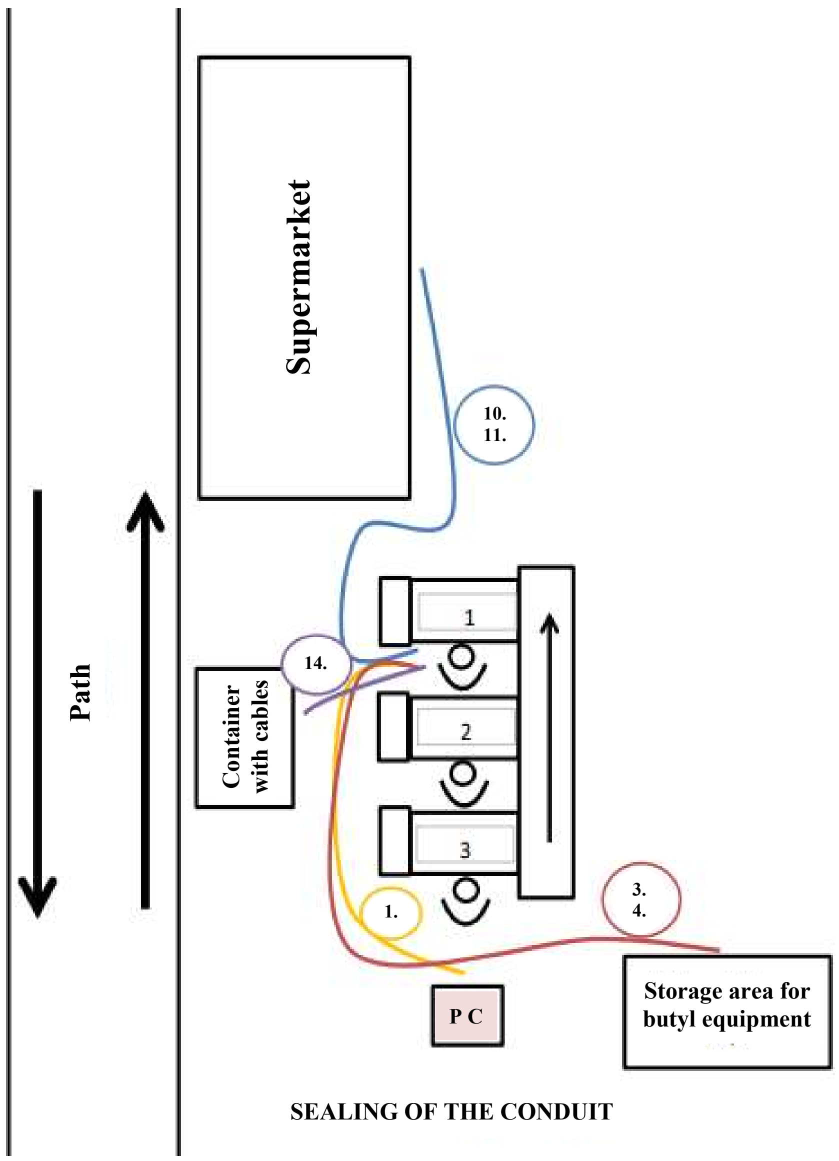

Figure 1. Spaghetti diagram of operator's mobility during changeover – real model

4. Conversion of internal operations into external operations at sealing station – alternative model

Because of the presence of the communication path close to sealing station, there is no possibility to change layout, also in terms of moving supermarket with components closer to workplaces. It was necessary to involve production workers in the changeover process. Some of the operations done by operators can be done by production workers. So that operators can operate machines. Components and equipment necessary for production of the next order can be prepared earlier by production workers and delivered on workplace also components and equipment from the previous order can be put back on site by production workers after changeover made by operators (Table 4).

Operations which require mobility of the operator, for example putting down and taking up new equipment, were transferred to production workers. This reduced the movement of operators to minimum.

In Table 5 there is presented list of operations and times during changeover after optimisation.

In Figure 2 there is presented, with the help of spaghetti diagram, the path of moving of the operator during preparing machines for the next order after taking into consideration proposed organisational and technical solutions. Operations were numbered according to list of operations presented in Table 1. Other operations, which were not marked in the diagram, the operator does on site (they do not require the mobility).

In the Figure 3 there is presented comparison of duration of operations connected with changeover before optimisation and after optimisation.

Table 4. List of operations and assignment of responsibility

Sin-gular	Before optimisation			After optimisation		
	Operation	**Opera-tor**	**Produc-tion worker**	**Operation**	**Opera-tor**	**Produc-tion worker**
1	End of order in the system and start of a new order	X		End of order in the system and start of a new order	X	
2	Dismantling of the handle that stabilises the position of coupling	X		Dismantling of the handle that stabilises the position of coupling	X	
3	Putting the equipment back in place	X		Putting the equipment back in place		X
4	Finding and retrieving suitable equipment	X		Finding and retrieving suitable equipment	X	
5	Connecting a new holder to stabilise the position of coupling	X		Connecting a new holder to stabilise the position of coupling	X	
6	Dismantling and assembly of remaining dice	X		Dismantling and assembly of remaining dice	X	
7	Setting the programme in the machine	X		Setting the programme in the machine	X	
8	Setting up the dispenser	X		Setting up the dispenser		X
9	Putting back the sealing strips from the containers into the bulk packaging	X		Putting back the sealing strips from the containers into the bulk packaging		X
10	Putting back the bulk packaging to supermarket	X		Putting back the bulk packaging to supermarket		X
11	Pickup the appropriate bulk packaging from the supermarket	X		Pickup the appropriate bulk packaging from the supermarket		X
12	Picking up sealing strips from bulk packaging to containers	X		Picking up sealing strips from bulk packaging to containers		X
13	Completing documentation and error sheet	X		Completing documentation and error sheet	X	
14	Cable collection	X		Cable collection	X	
15	Production and inspection 1 item	X		Production and inspection 1 item	X	
TOTAL		**15**	**0**	**TOTAL**	**9**	**6**

Table 5. List of operations and times during changeover after optimisation

Sin-gular	Operation	Operation time (1 machine)	Operation time (3 machines)	Time (total)	Path [m]	Path (total)	Internal operation	External operation	Comments
1.	End of order in the system and start of a new order	00:02:06	00:02:06	00:02:06	2	2		X	One of operators finishes and starts order in system
2.	Dismantling of the handle that stabilises the position of coupling	00:00:56	00:02:48	00:04:54	0	2	X		
3.	Putting the equipment back into trolley	00:00:03	00:00:09	00:05:03	4,5	6,5		X	Distance from the trolley for each operator is 1,5m
4.	Picking up appropriate equipment from the trolley	00:00:03	00:00:09	00:05:12	4,5	11		X	Distance from the trolley to workplace for each operator is 1,5m
5.	Connecting a new holder to stabilise the position of coupling	00:00:57	00:02:51	00:08:03	0	11	X		
6.	Dismantling and assembly of remaining dice	00:01:54	00:05:42	00:13:45	0	11	X		
7.	Setting the programme in the machine	00:00:34	00:01:42	00:15:27	0	11	X		
8.	Setting up the dispenser	00:00:18	00:00:54	00:16:21	0	11	X		
9.	Putting back the sealing strips into the trolley	00:00:08	00:00:24	00:16:45	0	11		X	

Table 5 (cont.). List of operations and times during changeover after optimisation

Sin-gular	Operation	Operation time (1 machine)	Operation time (3 machines)	Time (total)	Path [m]	Path (total)	Internal operation	External operation	Comments
10.	Picking up sealing strips for the new order from the trolley	00:00:08	00:00:24	00:17:09	3	14		X	
11.	Completing documentation and error sheet	00:00:53	00:02:39	00:19:48	0	14	X		
12.	Cable collection	00:00:07	00:00:21	00:20:09	4,5	18,5	X		The distance of the container with cables from each operator is 1,5m
13.	Production and inspection 1 item	00:01:06	00:03:18	00:23:27	0	18,5	X		
	TOTAL	00:09:13	00:23:27	00:23:27	18,5	18,5	8	5	

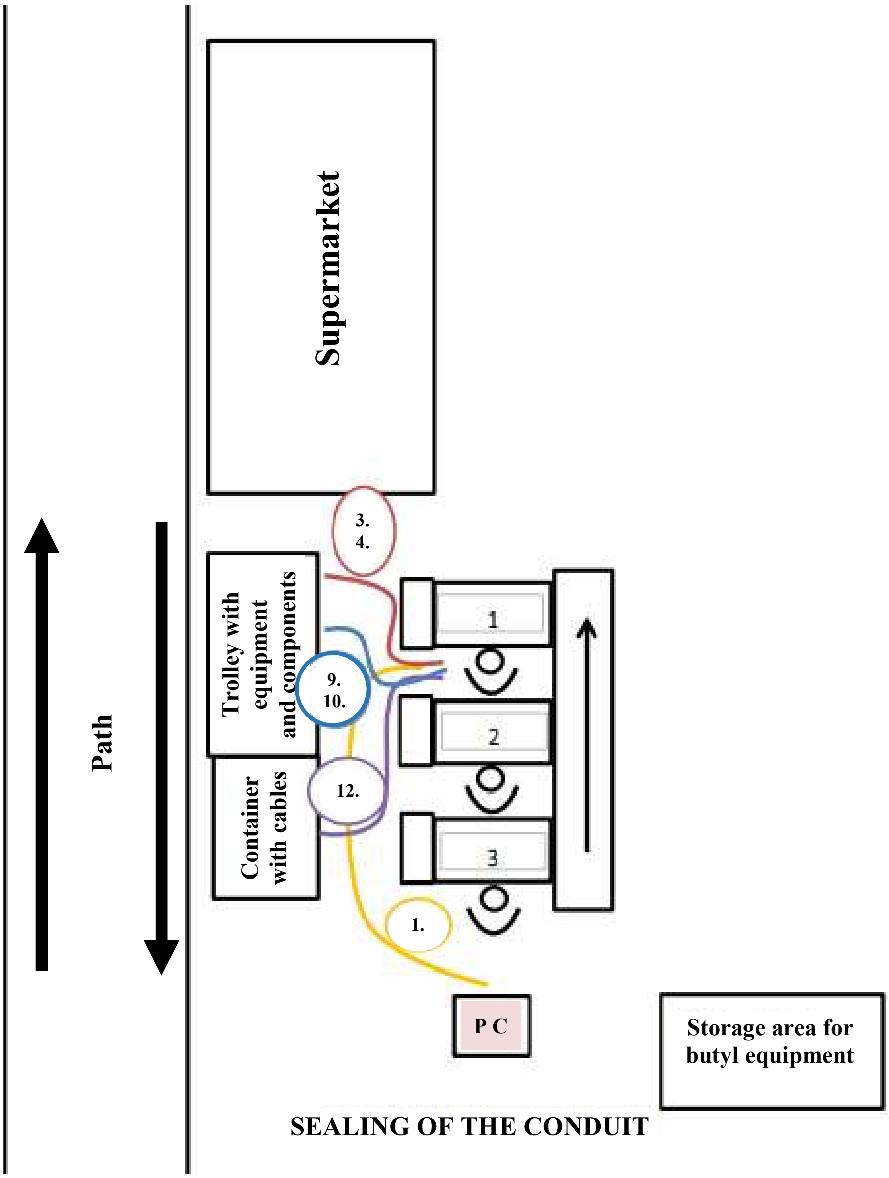

Figure 2. Spaghetti diagram of operator's mobility during changeover – alternative model

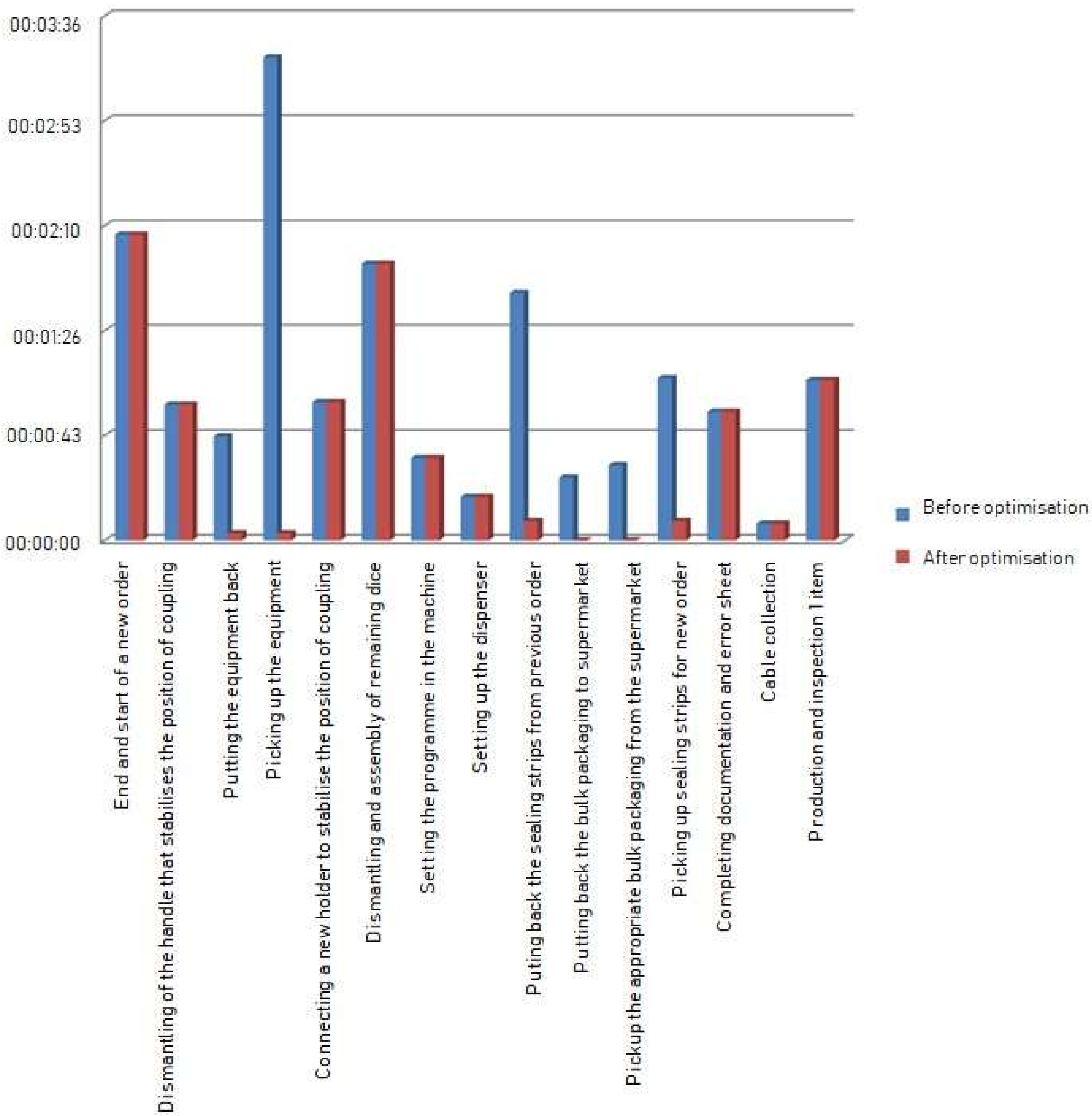

Figure 3. Comparison of duration of operations connected with changeover before optimisation and after optimisation.

5. Conclusion

Before optimisation, the operator was responsible for all operations connected with machine changeover (starting from removal of all unnecessary equipment and components from workplace, to supplying of the workplace with new components and equipment necessary for production of a new order). Involvement of production workers in changeover process helps to relieve the burden of the operator, which is beneficial. Changeover time of one machine has shortened from 16 min 39 sec to 9 min 13 sec which is 7 min 26 sec less. The operator can use saved time to produce cables. Taking into consideration necessary time to do the operation at this workplace, the operator can seal 6 cables more. On the assumption that average number of changeovers made during shift is 4, the operator saves 29 min 44 sec which results in the possibility of sealing 24 cables more. The distance for the operator during changeover the machine has shortened from 29,5 m to 18,5 m..

Bibliography

[1] Charron R., Harrington H.J., Voehl F., Wiggin H. 2014. *The lean management systems handbook* (Vol. 4). London: CRC Press.

[2] Coleman B.J., Vaghefi M.R. 1994. "Production and inventory management journal". *Heijunka (?): A key to the Toyota production system*, 35(4), 31.

[3] Helmold M. 2020. *Lean management and kaizen*. Springer international publishing.

[4] Jackson T.L. 1996. *Implementing a lean management system*. Portland: CRC Press.

[5] Krafcik J.F. 1988. "Sloan management review". *Triumph of the lean production system*, 30(1): 41-52.

[6] Liker J.K. 2004. *The Toyota way*. Madison: McGraw-Hill.

[7] Liker J.K. 2004. *Toyota way: 14 management principles from the world's greatest manufacturer*. Madison: McGraw-Hill Education.

[8] Lippolt Ch.R., Furmans K. 2008. Sizing of heijunka-controlled production systems with unreliable production processes. In: *Lean business systems and beyond*, 11-19. Springer, Boston.

[9] Ohno T. 1982. The origin of Toyota production system and kanban system. In: *Proceedings of the International Conference on Productivity and Quality Improvement*, 3-8. Industrial Engineering and Management Press Atlanta.

[10] Ohno T. 1990. *Toyota production system. Beyond large scale production*. New York: Productivity Press.

[11] Perry R.F., Gupta S.M. 1999. " International Journal of Operations and Production Management". *Flexible Kanban System,* 19 (10): 1065-1093.

[12] Pettersen J. 2009. "*The TQM Journal*" Defining lean production: some conceptual and practical issues. 21(2):127–142.

[13] Plenert G. 2010. *Reinventing lean: introducing lean management into the supply chain*. Oxford: Elsevier.

[14] Roriz C., Nunes E., Sousa S. (2017). "Procedia manufacturing". *Application of lean production principles and tools for quality improvement of production processes in a carton company* 11:1069-1076.

[15] Shing S., Dillon A.P. 2019. *A revolution in manufacturing: the SMED system*. New York: Routledge.

[16] Stadnicka D. 2015. "Management and Production Engineering Review". *Setup analysis: combining SMED with other tools* 6: 36-50.

[17] Wolniak R. 2014. "Zeszyty Naukowe. Organizacja i Zarządzanie/Politechnika Śląska". *Relationships between selected lean management tools and innovations*. (75): 157-166.

[18] Womack J.P, Jones D.T. 1996. *Lean thinking: Banish waste and create wealth in your corporation*. New York: Simon & Schuster.

[19] Womack J.P., Jones D.T., Roos D. 1991. *The machine that changed the world: How Japan's secret weapon in the global auto wars will revolutionize Western industry*. New York: HarperPerennial.

[20] Womack J.P., Jones D.T., Roos D. 2007. *The Machine That Changed The Word*. New York: Free Press.