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ASSEMBLY IMPROVEMENT WITH THE USE OF THE SCHMIGALLA METHOD

One of the important issues in production is the improvement of the assembly process, which involves the assembly of the product, as well as changeover and maintenance. Improving assembly, resulting from the appropriate layout of workstations, is crucial for both employees and robots performing routine assembly operations. This article discusses improving assembly using the Schmigalla method (also known as the Bloch-Schmigalla method or the triangular method), which is one of the heuristic layout planning methods. The article analyzes the selected assembly task and characterizes the main activities and equipment, on the basis of which the proper arrangement of equipment at the assembly station was determined. Based on the numerical data, the advantages of using the Schmigalla method to improve the location of the assembly station equipment are presented.

1. INTRODUCTION

The demand for new products that meet diverse customer needs, as well as the short life cycle of products on the market force manufacturers to change or modify products and production systems in a short time [1, 2].

Processes that are particularly important in manufacturing processes of multivariant products are changeovers requiring assembly and disassembly. The main terms used in this paper are assembly, which is understood as the process of joining parts to create a machine or other product, disassembly, which is understood as the process of separating a machine or structure into its individual parts, and changeover, which is understood as a change from one system, machine, method, etc. to another [3].

The assembly and disassembly process can include both product assembly and changeover and maintenance. The proposed Schmigalla method focusing on equipment location can be used in any type of assembly, but in improving changeover it can be combined with SMED.

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In the article improvement of the assembly process during changeover is focused on improving the organization of the workplace and the use of SMED (single minute exchange of dies) method.

Shortening of transport routes is one of the areas of improvement of the production process affecting its efficiency. Shortening of transport routes is important both in the process of production and changeover. One of the methods for determining the location of workstation equipment and minimizing the length of transport routes is the triangle method, also known as the Schmigalla method. The application of the Schmigalla method consists in obtaining and compiling data on the frequency of transport connections between localized objects, developing a theoretical distribution of objects and developing and implementing a spatial model, taking into account the dimensions of the hall, the dimensions of localized objects such as workstations, equipment or tools and transport routes.

Improving changeover, especially reducing changeover time, can increase flexibility, increase available capacity, and reduce costs. Reduction in changeover time can be achieved by using SMED [4–6].

Other methods useful for improvement include the balanced transportation problem optimization model proposed by Tae-Hyoung et al. [7], the DYNAMO virtual assembly tool used by Choi et al. [8], digital manufacturing and assembly systems discussed by Cohen et al. [9]. Santochi [10] discusses some issues regarding the application of CAPP systems in the fields of machining, assembly and disassembly. It is still a happy of effective and easy to use methods useful in manufacturing improvement. The combination of known methods can produce good results.

The purpose of this paper is to apply the Schmigalla method to improve the assembly process and, in particular, to reduce changeover time, which consists of assembly and disassembly tasks. The Schmigalla method has been combined with the SMED method, which is the primary method for reducing changeover time.

So far, the Schmigalla method has been used as a method to improve the plant layout. The novelty of the proposed approach is related to the use of Schmigalla method in the area of a single workstation and applies to tools and equipment.

The Schmigalla method is an important approach for layout improvement and is accepted from the point of view of computational complications.

The problem solved in this paper focuses on finding more efficient assembly and disassembly methods during changeovers.

The proposed approach consists of the following main steps:

– Improving the changeover process using SMED (identification of assembly and disassembly activities, classification of internal and external setup activities, transformation of some internal activities into external ones).
– Improving assembly and disassembly in the changeover process by improving material flow using the Schmigalla method.

Reducing assembly time is often achieved by using predetermined motion time systems (e.g., MTM) through simplified basic assembly movements, but this approach does not use any specific method to streamline motion. One of the most important variable attributes in assembly is motion distance. Thus, the combination of SMED and the Schmigalla method offers a systematic approach to improving assembly at changeover.

2. ASSEMBLY PROCESS IMPROVEMENT – THE PROPOSED APPROACH

2.1. CHANGEOVER IMPROVEMENT WITH THE USE OF SMED

One of the well-known methods used to improve changeover is SMED, which aims to reduce machine changeover time [11]. To implement SMED it is necessary to distinguish between internal and external changeovers. Internal changeovers are set-ups or operations performed while the machine is stationary, i.e. outside the time allocated for production. External set-ups are set-ups or operations performed when the machine is in full production. [11]

Authors discussing SMED, e.g. Cakmakci and Karasu [12], integrate SMED and time measurement methods (MTM), which provides both a motion study and standardization of the optimal changeover procedure [13]. In order to make improvements in changeover using SMED, the following factors should be considered: material used, machines, personnel, layout, etc. [11, 14–16]. SMED involves three main steps as follows [12, 17]:

Step 1: Separation of internal and external setup activities.

Step 2: Convert internal setup into external setup activities.

Step 3: Streamline all aspects of the setup operation.

This paper focuses on improving the assembly and disassembly system in the changeover process.

2.2. SET-UP PROCESS LAYOUT IMPROVEMENT WITH THE SCHMIGALLA METHOD

Improving the layout of a production process can affect its efficiency. The Schmigalla method assists in planning the layout of production processes and minimising the length of transport routes.

In the assembly process in changeovers it is necessary to minimise transport time and costs. The application of the Schmigalla method requires the preparation of data related to the deployment of objects, as well as theoretical and practical deployment of objects.

The concept of applying the Schmigalla method to assembly tasks in changeovers is shown in Fig. 1.

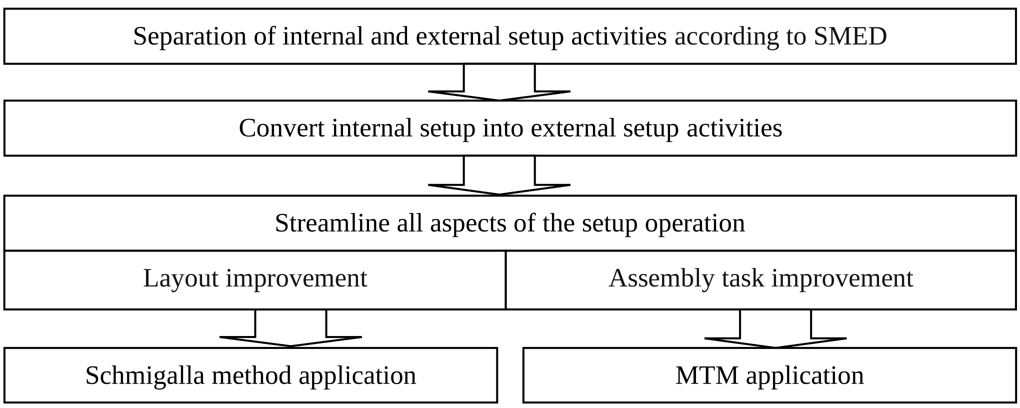


Fig. 1. The proposed approach

The Schmigalla method is one of the heuristic layout planning methods and consists of a network of equilateral triangles, where vertices represent potential workstations locations [18, 19].

The Schmigalla method can be based on the following stages [20]:

- Diagnosis – preliminary analysis, definition of the research subject.
- Modelling – defining operational processes, determining the frequency of transport connections between objects being located.
- Variant analysis – positioning of objects on a mesh of triangles.
- Detailed Design
- Implementation.

The preliminary analysis and definition the research subject are aimed at selecting the area whose reorganization can bring the greatest results. In the proposed approach, the aim of the analysis focuses on improving changeover and finding the best location for tools, equipment, and machine parts.

The choice of the research subject of the Schmigella method should be characterized by the following features:

- potential opportunities for savings in internal transport - shortening transport routes, reducing transport times,
- potential opportunities to change the internal transport system,
- potential opportunities to change assembly operations in the production process and/or changeovers,
- potential opportunities for changes in the layout of storage space, shelving, transport routes, ways of delivering and receiving materials to and from stations, storage space.

In the case of improving assembly in changeovers, the activities analysed according to the SMED method can be used in the preliminary analysis. The next step is modelling, which requires determining the frequency of transport connections. The modelling stage may be supported by the following methods: flow diagram, material flow diagram, transport matrix or Sankey diagram.

A Sankey diagram, also called a flow diagram, represents the flow rate between localized objects, taking into account the sum of the transport links that can be registered in the flow matrix. A more intensive material flow corresponds to a wider arrow representing the flow. An example of a Sankey diagram is shown in Fig. 2.

A process flow diagram (Fig. 3) is a graphical representation of a process, showing the flow of dynamic relationships in a system. Flow diagrams are used to represent the basic structure of elements and their interactions [21]. Another method useful in modelling transport flows is the flow matrix, which shows the number of connections between located objects (Fig. 4) [20, 22]. The next step in the Shmigalla method is variant analysis, that is positioning objects on a mesh of triangles.

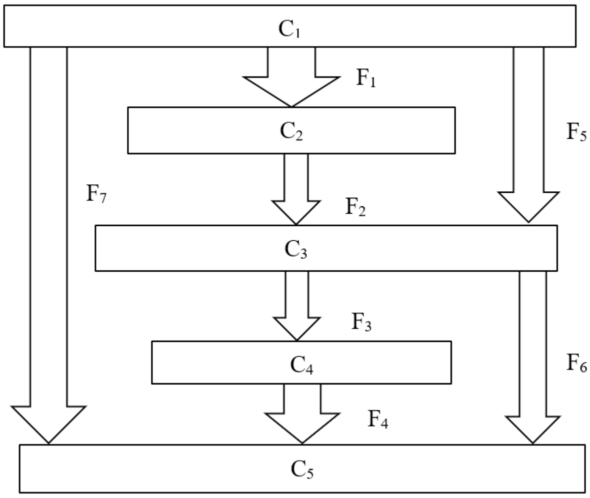
The variants of the position distribution can be analysed by means of the triangle method. The algorithm for placing the positions in the triangles method consists of the following steps [20, 22–25]:

A – selecting a pair of objects with the highest flow intensity,

B – placing the selected pair in the adjacent vertices of a triangle mesh,

C – finding the sum of connections between distributed and non-distributed objects, D – selecting the object with the highest flow intensity and placing it on the triangle mesh,

E – repeating steps C and D until all objects are arranged on the triangle mesh.



Where:
C_1, C_2,… – objects being located
F_1, F_2,… – transportation frequency

Fig. 2. An example of the Sankey diagram

No	Object being located / Changeover activity	C_1	C_2	C_3	C_4	C_5	…
		1	2	3	4	5	6
1	A_1						
2	A_2						
…	…						

Where:
A_1, A_2,… – changeover activity
C_1, C_2,… – objects being located
◯ – connection between changeover activity and parts, tools, equipment, etc. being located

Fig. 3. Flow diagram

Objects being located	C_1	C_2	…	C_n
C_1		$Lt_{1\text{-}2}$		$Lt_{1\text{-}n}$
C_2				$Lt_{2\text{-}n}$
…				
C_n				

Where:
C_1, C_2,.. – objects being located
$Lt_{1\text{-}2}$, $Lt_{1\text{-}n}$ – number of transports between objects being located

Fig. 4. A Flow matrix

Objects should be arranged in such a way that the objects with high flow intensity are located at a short distance from each other, and the distance is measured by the number of sides of the triangles on an equilateral triangle mesh.

The detailed design requires consideration of the actual dimensions of the workstations, equipment, shop floor and can be carried out using 2D modelling, 3D modelling or using physical models of the distributed elements, e.g. using 3D printing. At this stage, dimensionless points representing the workstations are assigned dimensions, which allows the layout of the workstations within the production hall to be planned. Due to the dimensions of the workstations, equipment and the production hall, the layout of the objects determined in the previous section may change.

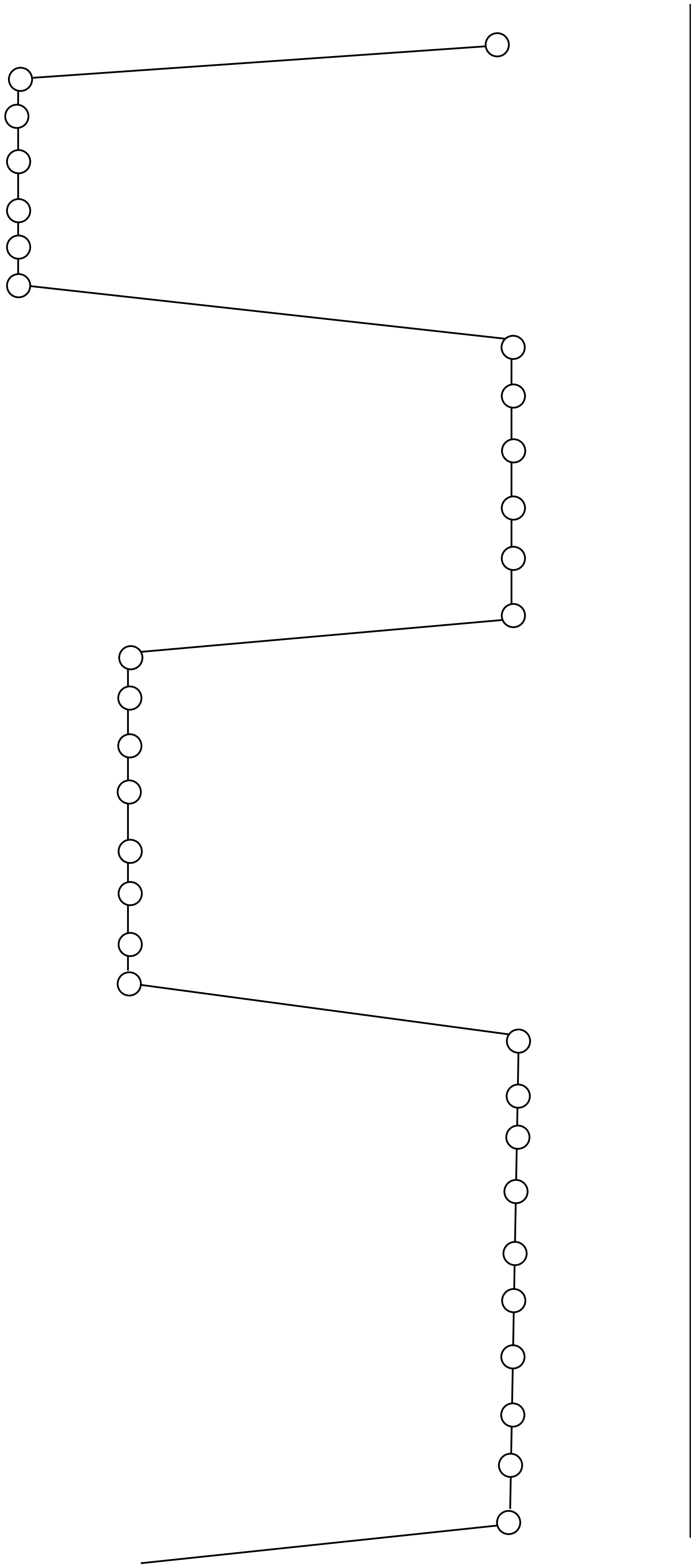
The next stage is implementation, which requires the setup of the workstations according to the plan determined in the previous stage. The implementation plan may include [26] time, financial and human resources.

3. AN EXAMPLE OF ASSEMBLY PROCESS IMPROVEMENT

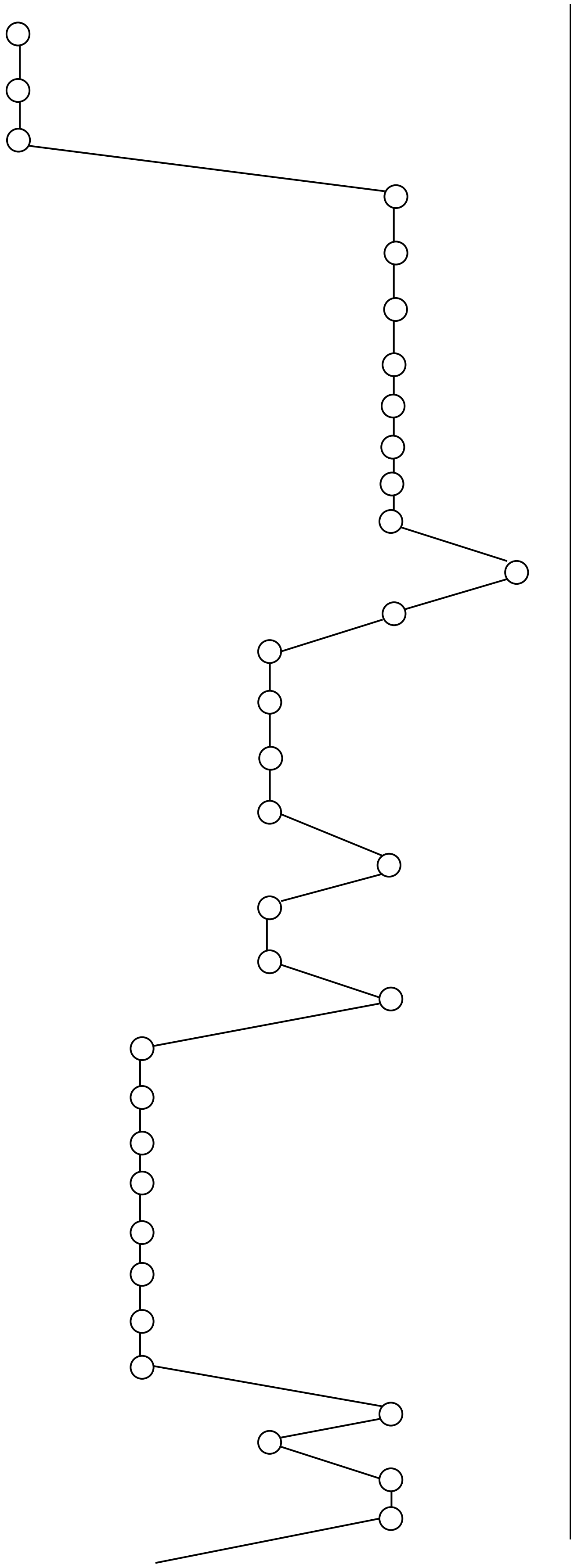
In the analysed changeover process the setting of the injection molding machine was improved by Wojtusiak [27] with the SMED method (Table 1). The changeover activities have been separated in the flow diagram presented in Fig. 5.

No	Parts and tools being located / Changeover activity	Core plate with ejector	Nest plate	Instrumentation plate (robot)	Cool-pick	Workstation	Tools
		1	2	3	4	5	6
1	Machine stop					○	
2	Delivery of a tool trolley under the machine						○
3	Hot runner cooling					○	
4	Entrance to the machine with tools to unscrew the core plate					○	
5	Unscrewing the screws from the ejector (2× M16)					○	
6	Installing a safety strip for the ejector (2×M10)					○	
7	Disconnecting the air hoses on the ejector (quick coupler)					○	
8	Detaching the water hoses (Cam-Lock connector)					○	
9	Installing a cube that allows the sling to be screwed in to pull out the core plate					○	
10	Screwing the ankle hook (M24)					○	
11	Suspension of the Core Plate on the crane					○	

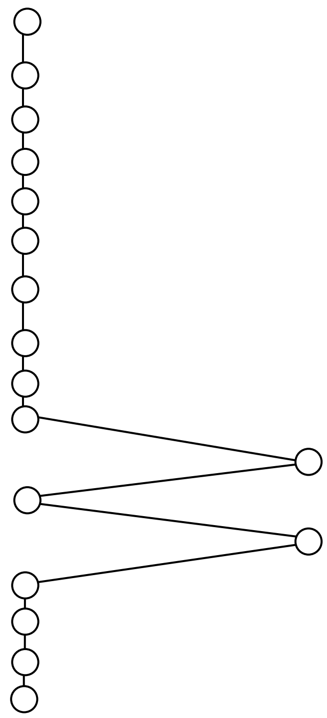
12	Unscrewing the screws securing the core plate (8×M20)
13	Removing the tool from the machine
14	Leaving the machine
15	Substitution of the Pallet for transporting the core plate
16	Placement of the Plate on the Pallet
17	Transport of the core plate to the shelf
18	Back to the machine
19	Entrance to the machine with the tools needed to remove the Nest Plate
20	Installing the hook of the sling in the hole intended for it
21	Attaching the sling to the hook and the overhead crane
22	Detaching the water hoses (Cam-Lock 2 'connector)
23	Unscrewing the socket plate mounting sscrews (21×M14)
24	Photo of the nest plate from the hot runner
25	Removing the tool from the machine
26	Exit the machine
27	Substitution of the pallet for transporting the nest plate
28	Location of the nest plate on the pallet
29	Transport of the core plate to the shelf
30	Substitution of another core plate under the machine
31	Placing the hook to the transport cube
32	Attaching the sling to the hook and the overhead crane
33	Inserting the core plate into the machine
34	Entering the machine
35	Screwing the core plate to the moving part of the machine (8×M20)
36	Tightening the Ejector Screws (2×M14)
37	Unscrewing the strip securing the ejector against slipping
38	Unscrewing the sling from the transport cube (Hook M24)
39	Unscrewing the Transport Cube (3×M14)
40	Connecting water hoses (2× Cam-Lock 2 ')
41	Connecting the air hoses to the ejector (quick coupler)
42	Exit the machine



43	Substitution of another nest plate under the machine
44	Installing the hook of the sling in the hole intended for it
45	Attaching the sling to the hook and the overhead crane
46	Inserting the nest plate into the machine
47	Screwing on the socket plate (21×M14
48	Screwing on the socket plate (21×M14)
49	Connecting water hoses to the Plate (2× Cam-lock 2 ')
50	Mold calibration
51	Mold cleaning
52	Machine start
53	Machine stop
54	Delivery of a tool trolley under the machine
55	Draining water from the system
56	Entry to the machine with tools to unscrew the cool-pick and the robot
57	Attaching the slings to the coolpick plate
58	Unscrewing the coolpick plate (16×M8)
59	Removing the coolpick plate from the machine
60	Putting the pallet under the machine
61	Placing the coolpick plate on the pallet
62	Unscrewing the sling from the plate
63	Entrance to the machine
64	Nscrewing the air-water collector from the robot (4×M8)
65	Unscrewing the strip with photocells (4×M6)
66	Mounting the sling to the robot
67	Connecting the crane to the robot
68	Unscrew the bolts securing the robot (6×M10)
69	Removing the robot from the machine
70	Placing the robot on the pallet with the cool-pick
71	Taking the tools to the shelf
72	Placing a new tool under the machine
73	Mounting the cool-pick sling
74	Inserting the tool into the machine
75	Entry into the machine



76	Screwing the tool to the moving part (16×M8)
77	Unscrewing the sling from the plate
78	Exit the machine
79	Connecting the crane to the robot
80	Inserting the tool into the machine
81	Entering the machine
82	Screwing the tool to the robot's arm (6×M10)
83	Unscrewing the sling from the plate
84	Screwing the water collector (4×M8)
85	Setting the photocells
86	Exit the machine
87	Open water valves
88	Closing machine guards
89	Robot calibration
90	Robot cleaning
91	Robot calibration
92	Robot clearing



Task removed according to SMED method

Fig. 5. A flow diagram of the changeover process

Table 1. Time saving with the use of SMED

	Time [h]
Before SMED	18.2
After SMED	13.92

Based on the flow diagram, a flow matrix was created (Fig. 6) and the number of transitions between localized objects was determined.

Objects being located	C1	C2	C3	C4	C5	C6
C1					2	
C2					4	
C3					7	
C4					6	
C5						4
C6						

Fig. 6. The flow matrix

The Sankey diagram shown in Fig. 7 represents the material flow rate during the change-over process.

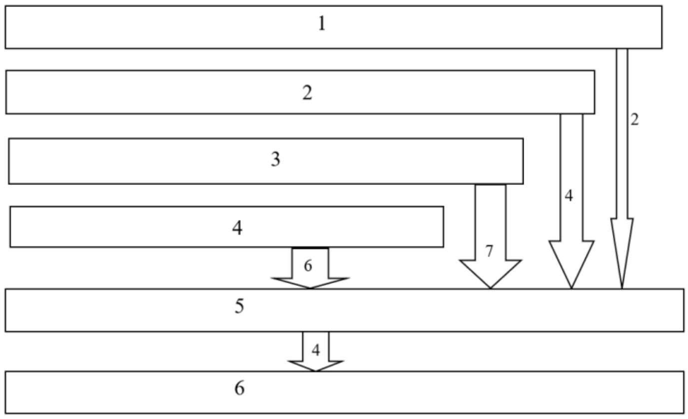


Fig. 7. The Sankey diagram

The order of placing objects on the triangle mesh is shown in Fig. 8.

Objects being located	1	2	3	4	5	6
3					7	
5	2	4		6		4
4					6	
2						
6						
1						

Fig. 8. Calculation for selection of successive positions in the triangular mesh

Figure 9 shows the proposed layout of objects in the triangle mesh model.

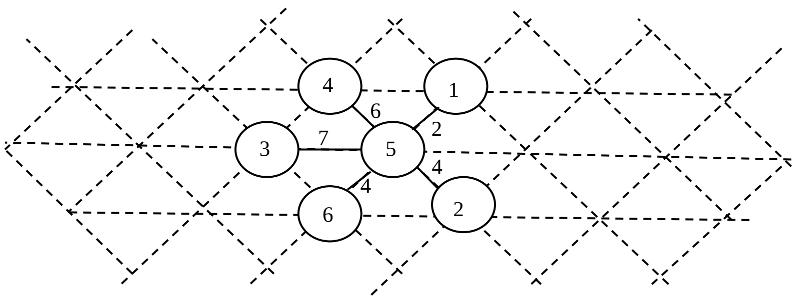


Fig. 9. Triangle mesh

The proposed injection moulding machine changeover layout was presented in Fig. 10.

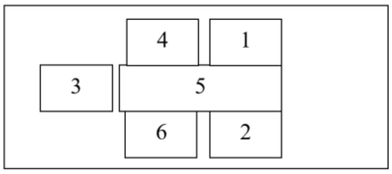


Fig. 10. The proposed workstation layout

Time saving after layout improvement was calculated with the use of MTM (Table 2) and is 4.32 min.

Table 2. Time saving calculation

No	Changeover activity	Time reduction with the use of Schmigalla method [min]
1	Machine stop	
2	Delivery of a tool trolley under the machine	
3	Hot runner cooling	
4	Entrance to the machine with tools to unscrew the core plate	
5	Unscrewing the screws from the ejector (2× M16)	
6	Installing a safety strip for the ejector (2× M10)	
7	Disconnecting the air hoses on the ejector (quick coupler)	
8	Detaching the water hoses (Cam-Lock connector)	
9	Installing a cube that allows the sling to be screwed in to pull out the core plate	
10	Screwing the ankle hook (M24)	
11	Suspension of the Core Plate on the crane	
12	Unscrewing the screws securing the core plate (8×M20)	
13	Removing the tool from the machine (distance reduction from 4 m to 1 m)	–0.27
14	Leaving the machine	
15	Substitution of the Pallet for transporting the core plate	
16	Placement of the Plate on the Pallet	
17	Transport of the core plate to the shelf	
18	Back to the machine (distance reduction from 4 m to 1 m)	–0.27
19	Entrance to the machine with the tools needed to remove the Nest Plate	
20	Installing the hook of the sling in the hole intended for it	
21	Attaching the sling to the hook and the overhead crane	
22	Detaching the water hoses (Cam-Lock 2 'connector)	
23	Unscrewing the socket plate mounting screws (21×M14)	
24	Photo of the nest plate from the hot runner	
25	Removing the tool from the machine (distance reduction from 4 m to 1 m)	–0.27
26	Exit the machine	
27	Substitution of the pallet for transporting the nest plate	
28	Location of the nest plate on the pallet	
29	Transport of the core plate to the shelf	
30	Substitution of another core plate under the machine	
31	Placing the hook to the transport cube	
32	Attaching the sling to the hook and the overhead crane (distance reduction from 4 m to 1m)	–0.27
33	Inserting the core plate into the machine	
34	Entering the machine	
35	Screwing the core plate to the moving part of the machine (8×M20)	
36	Tightening the Ejector Screws (2×M14)	
37	Unscrewing the strip securing the ejector against slipping	
38	Unscrewing the sling from the transport cube (Hook M24)	

39	Unscrewing the Transport Cube (3×M14)	
40	Connecting water hoses (2× Cam-Lock 2 ')	
41	Connecting the air hoses to the ejector (quick coupler)	
42	Exit the machine (distance reduction from 4 m to 1 m)	–0.27
43	Substitution of another nest plate under the machine	
44	Installing the hook of the sling in the hole intended for it	
45	Attaching the sling to the hook and the overhead crane (distance reduction from 4 m to 1 m)	–0.27
46	Inserting the nest plate into the machine	
47	Screwing on the socket plate (21×M14)	
48	Screwing on the socket plate (21×M14)	
49	Connecting water hoses to the Plate (2× Cam-lock 2')	
50	Mold calibration	
51	Mold cleaning	
52	Machine start	
53	Machine stop	
54	Delivery of a tool trolley under the machine	
55	Draining water from the system	
56	Entry to the machine with tools to unscrew the cool-pick and the robot	
57	Attaching the slings to the coolpick plate	
58	Unscrewing the coolpick plate (16×M8)	
59	Removing the coolpick plate from the machine (distance reduction from 4 m to 1 m)	–0.27
60	Putting the pallet under the machine (distance reduction from 4 m to 1 m)	–0.27
61	Placing the coolpick plate on the pallet	
62	Unscrewing the sling from the plate(distance reduction from 4 m to 1 m)	–0.27
63	Entrance to the machine	
64	Unscrewing the air-water collector from the robot (4×M8) (distance reduction from 4 m to 1 m)	–0.27
65	Unscrewing the strip with photocells (4×M6)	
66	Mounting the sling to the robot	
67	Connecting the crane to the robot	
68	Unscrew the bolts securing the robot (6×M10)	
69	Removing the robot from the machine	
70	Placing the robot on the pallet with the cool-pick	
71	Taking the tools to the shelf (distance reduction from 4 m to 1 m)	–0.27
72	Placing a new tool under the machine (distance reduction from 4 m to 1 m)	–0.27
73	Mounting the cool-pick sling	
74	Inserting the tool into the machine	
75	Entry to the machine (distance reduction from 4 m to 1 m)	–0.27
76	Screwing the tool to the moving part (16×M8)	
77	Unscrewing the sling from the plate	
78	Exit the machine	
79	Connecting the crane to the robot	
80	Inserting the tool into the machine	
81	Entering the machine	
82	Screwing the tool to the robot's arm (6×M10)	

83	Unscrewing the sling from the plate	
84	Screwing the water collector (4×M8)	
85	Setting the photocells (distance reduction from 4 m to 1 m)	–0.27
86	Exit the machine (distance reduction from 4 m to 1 m)	–0.27
87	Open water valves (distance reduction from 4 m to 1 m)	–0.27
88	Closing machine guards (distance reduction from 4 m to 1 m)	–0.27
89	Robot calibration	
90	Robot cleaning	
91	Robot calibration	
92	Robot cleaning	

4. CONCLUSION

An important issue is the development of methods useful in improving production. Methods such as SMED and Schmigalla can be used together to facilitate assembly and disassembly during changeover. The proposed approach helps to answer the following questions: what tasks are necessary for changeover and how to locate equipment and tools. The block diagram of the changeover process has been proposed as a method of combining SMED and the Schmigalla method.

It seems that the application of the Schmigalla method is useful for improving assembly and disassembly activities in the area of a given workplace. The presented approach uses the Schmigalla method, also known as the triangle method, to improve changeover and proposes an appropriate algorithm. While this approach is useful in improving the layout of workplaces, the primary application of the Schmigalla method focuses on improving the layout between workstations.

In the presented approach, SMED includes the following steps: separate internal and external configuration activities, convert internal configuration to external configuration activities, streamline all aspects of configuration operations. The process of improving the layout using the Schmigalla method began with the diagnosis, which consisted in conducting an initial analysis and defining the research topic. The next step was modelling, which required the definition of operational processes and determination of the frequency of transport connections between the objects to be located, and then variant analysis consisting in positioning the objects on a triangle mesh. The final step is detailed design and implementation.

The approach discussed in the article is presented on a practical example that presents a proposal to improve the configuration of the injection moulding machine.
Finally, the proposed approach using the Schmigalla method can be useful for both manual and robotic assembly using e.g. cobots (collaborative robots) that work hand in hand with people.

The existing assembly improvement methods described e.g. by Ho et al. [28] included: mathematical programming (Linear Programming, Integer Linear Programming, Nonlinear Programming) and metaheuristic (Simulated Annealing, Tabu Search, Genetic Algorithms). These methods addressed: setup management (line assignment; machine grouping; product grouping; product sequencing) and process optimization (component allocation; component sequencing; feeder arrangement). In future studies, the proposed approach will be compared with other improvement methods.

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