

Reduction of Machine Setup Time

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Customers today require smaller series of products. In manufacturing companies, this increases machine setup time, which is a waste.

This paper presents a procedure for organizing and implementing a reduction of machine setup time. It is based on teamwork and uses the SMED method, which allows a gradual reduction of machine setup time to less than 10 minutes, and a continuous improvement system.

The paper also presents the results of the organization and execution of a SMED workshop for the reduction of setup times in a jet machine, as well as first suggestions for improvements that should significantly reduce machine setup time.

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0 INTRODUCTION

In the 1950s, Taiichi Ohno, the legendary president of Toyota, was very unhappy because his company produced cars for stock. The cars were driven from the manufacturing hall to a parking lot, where they waited for customers. T. Ohno considered that this waiting of cars for customers was a waste that should be eliminated, or at least reduced. He found that the waste was caused by manufacturing components and final products (cars) in excessively large series.

The equation for calculating the time required for manufacturing a series of parts and the assembly of components is:

$$t = t_s + m \cdot t_1 \quad (1)$$

where:

- t time required for manufacturing parts and assembling components [Nh/series]
- t_s machine setup time or assembly workplace setup time [Nh/series]
- m number of units within a series [pieces/series]
- t_1 manufacturing/assembly time per unit [Nh/piece].

Analysis of this equation led Ohno to the conclusion that the company could make a transition from large series manufacturing to small series only if they could substantially reduce the setup times of machines and assembly workplaces.

The task of finding a suitable method for reducing setup time was given to Shigeo Shingo, who is the author of the rapid machine setup method, also known as SMED (single minute exchange of dies) [1].

The SMED method is one of the lean manufacturing methods or tools [1], which allow successful competition in domestic and foreign markets (Fig. 1).

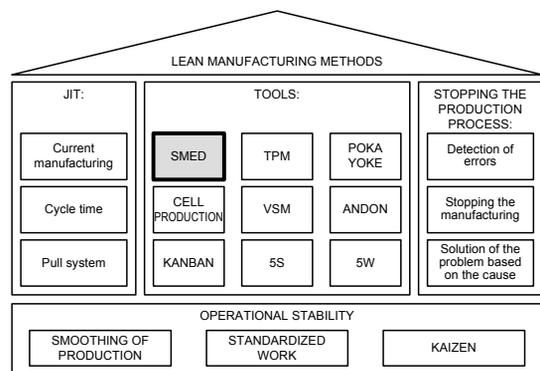


Fig. 1. Lean manufacturing methods and tools

Van Goubergen says [2] that it is very important to reduce machine setup time during the implementation of lean manufacturing because this time has a significant impact on manufacturing costs due to decreasing sizes of series orders.

Van Goubergen justifies the reduction of machine setup time by [2]:

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- greater flexibility of the company (the company can offer customers more products and their variants in smaller series),
- higher throughput through company bottlenecks (reduced setup times of bottleneck machines ensure higher throughput),
- increased efficiency of the company (by reducing machine setup time, the efficiency of these machines increases, which increases company income).

The quality of machine setup is defined by three parameters [2]:

- the method used for machine setup (how),
- organization of work needed for machine setup (who, what, when),
- technical aspects of tools and devices,
- as presented in Fig. 2.

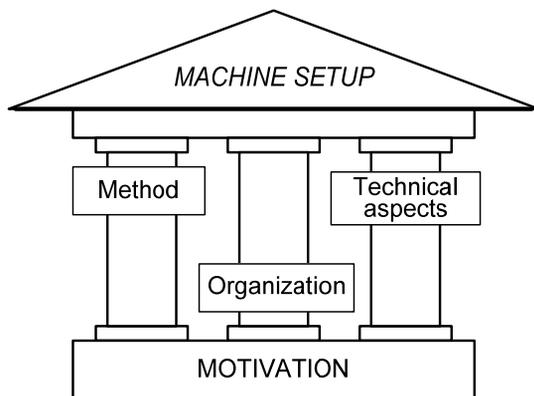


Fig. 2. Elements of machine setup

Rapid and efficient machine setup requires optimal values of all three elements of machine setup, supported by the motivation of the personnel that carry out machine setup.

Quality and machine setup time also depend on machine design.

A company can select one of three options [3] to [5]:

- design of a new machine that will ensure minimum setup time - large investment,
- improvement of an existing machine and the use of the SMED method to achieve a setup time of 3 minutes,
- use of the SMED method to achieve a setup time of less than 10 minutes.

Fig. 3 shows the relations between machine setup time and costs with these three strategies [3].

It can be seen from Fig. 3 that a reduction of machine setup time using the SMED method is cheap, but has only limited effects. The design of a new machine is expensive, but the new setup time will be very short. Taking into account both costs and setup time, it is most efficient for the company to select the SMED method and to make improvements to the machines.

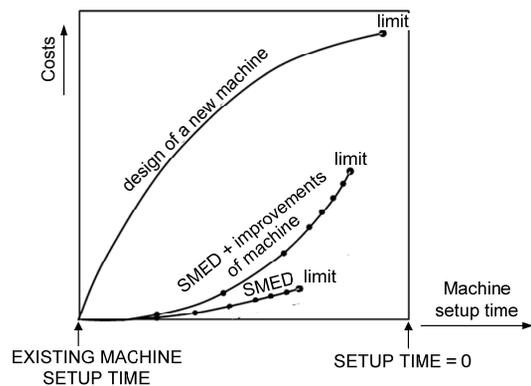


Fig. 3. Dependency between machine setup time and costs

1 ORGANIZATION AND EXECUTION OF SMED WORKSHOP

The goal of a SMED workshop is to reduce machine setup time and thus increase machine availability.

Experience in using the SMED method has shown that teamwork is essential for its successful implementation. When selecting team members to participate in the organization and execution of a SMED workshop, it is necessary to ensure that all nine team roles defined by Dr. Belbin are occupied [6].

A review of the literature [3], [7] and [8] and our experience obtained in introducing the SMED method in companies have led us to the creation of a procedure for the organization and execution of a SMED workshop for the reduction of machine setup time (Fig. 4).

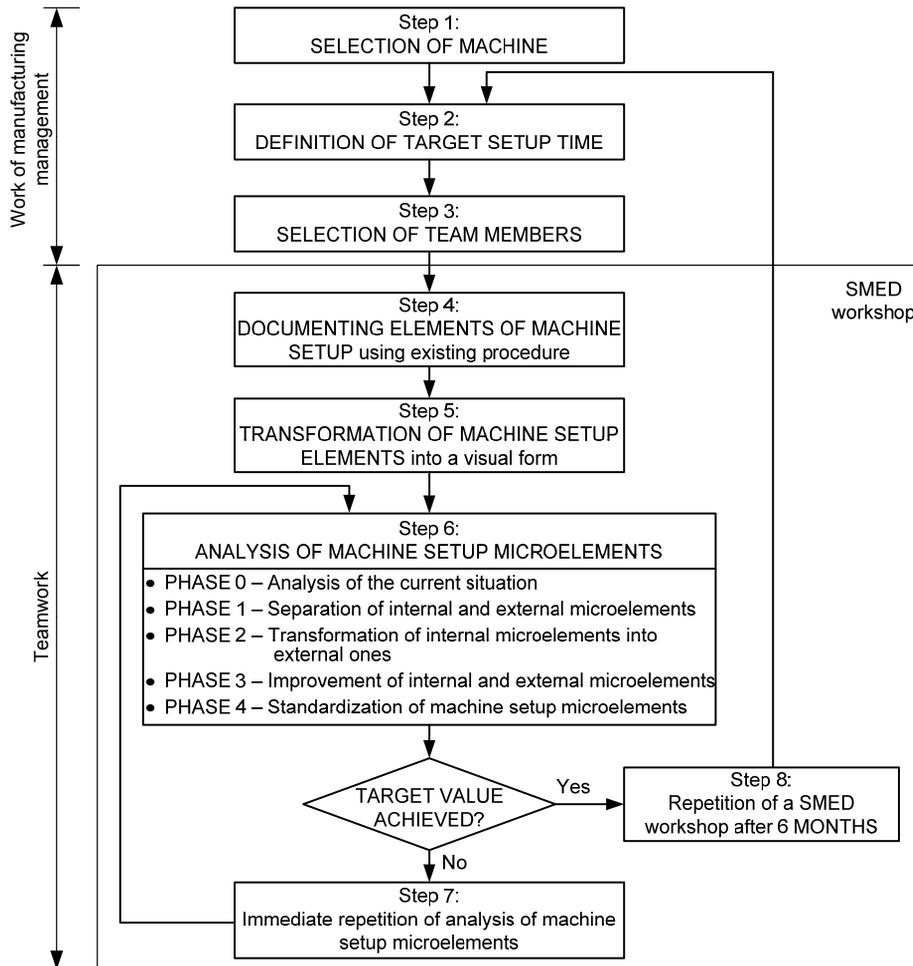


Fig. 4. Procedure for the organization and execution of a SMED workshop

Step 1: SELECTION OF THE MACHINE
 Manufacturing management selects the machine for reduction of setup time by taking into account the pre-defined criteria (e.g., the longest machine setup time, frequency of setup, bottleneck machines).

Selection is made on the basis of ABC analysis [9].

Step 2: DEFINITION OF TARGET SETUP TIME

The definition of the target value for reduced setup time is very important, since it directly influences the motivation of team members who will carry out the SMED method.

Manufacturing management usually specifies that the team should reduce the setup

time by 50% during the first SMED workshop (Fig. 5).

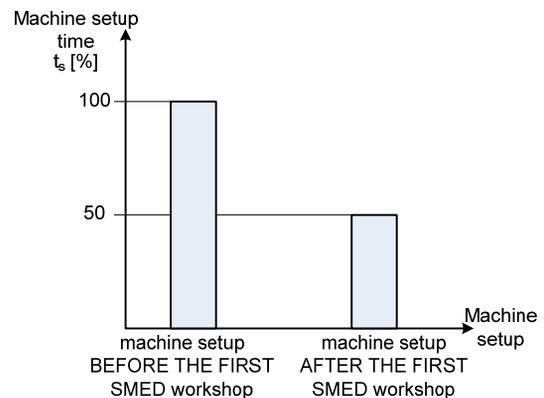


Fig. 5. Target setup time

It is difficult to improve this result in each consecutive SMED workshop, except when a new team member appears with revolutionary (and not too expensive) ideas [10] and [11].

Step 3: SELECTION OF TEAM MEMBERS

Team members that will participate in the execution of a SMED workshop are selected by the manufacturing management. The team should include representatives from manufacturing planning and management departments, workers who are responsible for machine setup and processing of orders, and maintenance personnel.

After carrying out the Belbin test of team roles [12] the manufacturing management appoints:

- a TEAM LEADER, responsible for leading the team, organization and documentation of team sessions and for achieving agreement within the team,
- a TEAM MODERATOR, who is the SMED method expert and who will lead the team from step 4 to step 7 of the SMED workshop,
- other team members:
 - a setup operator, who will carry out the machine setup as it has been done up to that point,
 - a protocol writer, who will take notes on machine setup elements,
 - a time recorder operator, who will record the time required for machine setup elements,
 - a photographer, who will take photos of details of machine setup elements,
 - a cameraman, who will use a video camera to film the execution of all machine setup

elements,

- a team member to draw a diagram of the path made by the setup operator.

Manufacturing management informs the selected team members and their heads about the date of the SMED workshop. They confirm their approval by signing the "SMED workshop order" form (Table 1).

Step 4: DOCUMENTING ELEMENTS AND MICROELEMENTS OF MACHINE SETUP USING THE EXISTING PROCEDURE

The existing machine setup procedure is carried out and documented. The actual sequence and execution time of machine setup elements/microelements are defined.

The following tools are available for documenting the elements and microelements of machine setup:

- notebook of machine setup elements,
- monitoring paper,
- list of paths made by the machine setup operator,
- photos of machine setup details,
- video film of the entire machine setup process.

A notebook with the elements and microelements of the machine setup is the simplest tool for documenting the sequence and timing of setup elements/microelements. The protocol writer enters the elements and microelements of the machine setup in the notebook.

The data are entered in the exact sequence of the setup, with the exact times noted, as reported by the time recorder operator.

Table 1. SMED workshop order

SMED workshop order				
Ordered by:				
Workshop name				
Workshop date		from		to
Workshop goals				
Management:	Signature:	Team members:	Department:	Signature:
:	:	:	:	:
Date of meeting:		Date of workshop presentation		Manufacturing manager:

The monitoring paper is a form on which the protocol writer enters the following data:

- sequential numbers of machine setup elements and microelements,
- short description of machine setup elements and microelements,
- cumulative times of machine setup elements and microelements,
- individual times of machine setup elements and microelements,
- histogram of individual times of machine setup elements and microelements.

The purpose of the list of paths made by the setup operator is to visualize unnecessary movements of the operator during setup. The basis for the list of paths is a drawing of the workplace. The movements of the setup operator are drawn onto it with a continuous line.

During the subsequent analysis of the elements and microelements of the machine setup and on the basis of the list of actual paths made by the setup operator, the team can establish necessary paths and eliminate unnecessary ones.

Photos of details of machine setup elements and microelements are taken with a high-definition digital camera with zoom. The photographer should be careful not to be in the way of the setup operator.

A video camera is the most effective tool for recording the machine setup. For this purpose, a camera with a hard disk capacity of at least 120 GB and a battery for at least 50 hours of filming is required. Filming starts at the beginning of the execution of the first machine setup element/microelement and ends with the completion of the last element (without interruption). SMED team members can view the machine setup video several times and analyze it thoroughly.

Step 5: TRANSFORMATION OF MACHINE SETUP ELEMENTS AND MICROELEMENTS INTO A VISUAL FORM

The data obtained on the machine setup elements and microelements are copied from the notebook to stickers that can be affixed to a panel during the next step.

Step 6: ANALYSIS OF MACHINE SETUP ELEMENTS AND MICROELEMENTS

Analysis of machine setup elements and microelements is carried out by the team in a

room with a large panel, which allows the affixing of stickers, and chairs placed around in a semicircle.

Analysis is carried out in a sequence of phases as presented in Fig. 6.

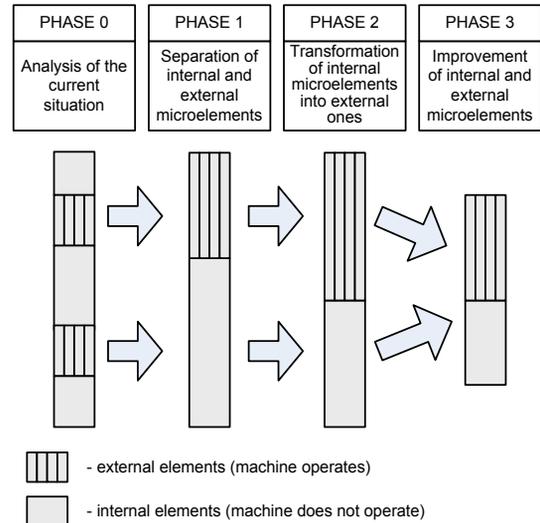


Fig. 6. Analysis phases of setup elements and microelements

Phase 0: Analysis of the current situation

Before the meeting, the team moderator brings into the meeting room all stickers of machine setup elements and microelements, with their duration times, labeled as X or E. An X label on the microelement sticker indicates that another microelement follows this one, while an E label denotes that this is the last microelement.

At the beginning of the session, the moderator projects onto the panel the analytical card for entering the current situation of machine setup. By affixing stickers onto the panel (with the agreement of the team members) the current situation of machine setup is obtained.

Phase 1: Separation of internal and external microelements

The moderator presents every microelement of a particular element in the current machine setup and the team members must decide whether the microelement is:

- internal (it can be carried out only during machine shutdown) or
- external (it can be carried out during machine operation).

The moderator marks the stickers of internal microelements with red and those of external microelements with yellow.

Phase 2: Transformation of internal microelements into external ones

The moderator (with the cooperation of the team) moves the yellow stickers either to column 1 (starting activities) or to column 5 (completion activities).

Phase 3: Improvement of internal and external microelements

By carrying out several creativity workshops [12] the team obtains suggestions for improvements of internal and external microelements.

The moderator enters all improvements of machine setup microelements into the lower part of the analytical card ("improvements" field).

Phase 4: Standardization of machine setup microelements

In this phase, standardization of internal and external microelements is carried out, and a continuous improvement principle is put into effect.

Training is organized for setup operators, machine operators and maintenance workers. Machine setup according to the improved procedure is carried out at least three times during this training.

Step 7: IMMEDIATE REPETITION OF THE ANALYSIS OF ELEMENTS AND MICROELEMENTS

If the target setup time defined in step 2 has not been achieved, the team immediately repeats the analysis of machine setup microelements.

Step 8: REPETITION OF THE SMED WORKSHOP

Reduction of machine setup time is a never-ending process, so it is necessary to repeat the SMED workshop every six months and in this way get closer to the set goal of "achieving a machine setup time shorter than 10 minutes".

2 CASE STUDY OF JET-MACHINE SETUP TIME REDUCTION

The manufacturing management decided that the company would test the SMED workshop in order to reduce machine setup time.

Step 1: SELECTION OF THE MACHINE

The manufacturing management used the following criteria during machine selection:

- machine setup times in the last three months,
- number of machine setups in the last three months.

Using a weighted-scoring method, the manufacturing management decided that a reduction of setup time would be tested on a KM 800 – CNC Injection Molding Machine, Craus-Maffei (Fig. 7).



Fig. 7. KM 800-CNC injection molding machine

Step 2: DEFINITION OF TARGET SETUP TIME

The time recorder operator measured the time required for machine setup: 119.97 minutes.

The manufacturing management decided that the target reduced setup time would be 60 minutes, i.e., 50% of the current value.

Step 3: SELECTION OF TEAM MEMBERS

The manufacturing management selected an 8-member team for the SMED workshop:

- a team leader from the operation logistics department,
- a team moderator from the technology department,
- team members,
- a setup operator from the manufacturing department,
- a protocol writer from the planning department,

Table 2. *Monitoring paper - standard machine setup procedure*

MONITORING PAPER																		
Element number	DESCRIPTION OF THE ELEMENT	Cumulative time			Individual time [sec]	HISTOGRAM OF INDIVIDUAL TIMES [sec]												
		hour	min	sec		10	20	30	40	50	60	70	80	90	100			
1	Machine shutdown	0	00	31	31	█	█	█										
2	Setup of the manipulat.	0	01	12	41	█	█	█	█									
3	Walk to the office	0	01	26	14	█	█											
4	Searching for documentation	0	01	35	9	█												
5	Walk to the machine	0	01	50	15	█	█											
:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
55	Confirmation of first samples	1	59	04	80	█	█	█	█	█	█	█	█	█				

- a time recorder operator from the manufacturing department,
- a photographer from the manufacturing department,
- a cameraman from the supply department,
- a drawer of paths made by the setup operator from the process control department.

The manufacturing management sent the "SMED-workshop order" form to departmental heads and team members for them to confirm their agreement with participation in the workshop.

Step 4: DOCUMENTING ELEMENTS AND MICROELEMENTS OF JET-MACHINE SETUP (existing procedure)

During the actual machine setup, the protocol writer entered the sequence of elements and microelements of machine setup into his notebook. He also noted exact setup times, reported by the time recorder operator.

After recording the machine setup elements, the protocol writer entered the data on the monitoring paper (Table 2).

The drawer of the paths made by the setup operator made a drawing of the operator's movements. The results are presented in Fig. 8.

It is obvious that the setup operator is disorganized and that he often leaves his workplace and walks around unnecessarily.

During machine setup, photos of the microelement details were taken with a Sony Cybershot DSC-H98MP camera. The whole

machine setup was filmed with a Sony HDR-XR200 video camera equipped with a high-capacity battery and high-capacity film memory.

Step 5: TRANSFORMATION OF JET-MACHINE SETUP ELEMENTS AND MICROELEMENTS INTO A VISUAL FORM

The data obtained on the jet-machine setup elements and microelements were copied from the notebook to stickers to be affixed to a panel during the next step. The stickers were labeled as X - if there was another microelement after the current one, E - if the current microelement was the last one.

Step 6: ANALYSIS OF JET-MACHINE SETUP ELEMENTS AND MICROELEMENTS

Phase 0: Analysis of the current situation of jet-machine setup

At the beginning of the session, the moderator projected the analytical card for entering the current situation onto the panel. By affixing stickers to the panel (in agreement with other team members) the current situation of jet-machine setup was obtained (Table 3).

Phase 1: Separation of internal and external setup microelements

The moderator presented each microelement of the current machine setup and the team decided whether the microelement was internal or external.

Table 3. Analytical card of the current situation of jet-machine setup

ANALYTICAL CARD – CURRENT SITUATION						
Machine setup element	EXTERNAL ELEMENTS	INTERNAL ELEMENTS			EXTERNAL ELEMENTS	TOTAL TIME [min]
	1. Starting activities	2. Tool dismantling procedure	3. Tool mounting procedure	4. Start of the machine	5. Completion activities	
Element duration [min]	0	19.30	93.97	6.70	0	
MICROELEMENTS		Machine shutdown 31 sec X	Fixing the crane clamps 69 sec X	Test of the jet operation 117 sec X		
		Manipulator setup 41 sec X	Insertion of a new tool 29 sec X	Synchronization of jet-machine 166 sec X		
		Walk to the office 14 sec X	Centering the tool position 164 sec X	Confirmation of the first samples 81 sec E		
		Lifting the previous tool from the machine 89 sec E	Entering the data into the documentation 385 sec X			
			Tool heating 3811 sec X			
			Spraying the cylinder 72 sec E			

Table 4. Analytical card for separation of internal and external microelements

ANALYTICAL CARD – separation of elements						
Machine setup element	EXTERNAL ELEMENTS 	INTERNAL ELEMENTS 			EXTERNAL ELEMENTS 	TOTAL TIME [min]
	1. Starting activities	2. Tool dismantling procedure	3. Tool mounting procedure	4. Start of the machine	5. Completion activities	
Element duration [min]	0	19.30	93.97	6.70	0	119.97
MICROELEMENTS		Machine shutdown 31 sec X 	Fixing the crane clamps 69 sec X 	Test of the jet operation 117 sec X 		
		Manipulator setup 41 sec X 	Insertion of a new tool 29 sec X 	Synchronization of jet-machine 166 sec X 		
		Walk to the office 14 sec X 	Centering the tool position 164 sec X 	Confirmation of the first samples 81 sec E 		
		Lifting the previous tool from the machine 89 sec E 	Entering the data into the documentation 385 sec X 			
			Tool heating 3811 sec X 			
			Spraying the cylinder 72 sec E 			
DURATION OF INTERNAL ELEMENTS [min]	0.00	12.40	24.67	6.70	0.00	43.77
DURATION OF EXTERNAL ELEMENTS [min]	0.00	6.90	69.30	0.00	0.00	76.20

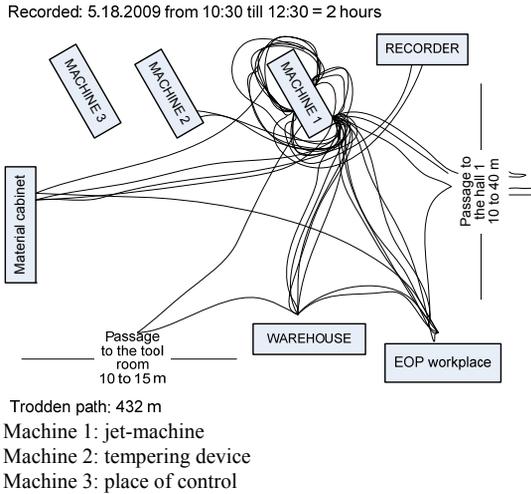


Fig. 8. List of paths made by the setup operator - standard machine setup procedure

The moderator marked the stickers of internal microelements with red and those of external microelements with green (Table 4).

The team members found that it would be possible to carry out 76.2 minutes (out of the total 119.97 minutes) of setup during the jet-machine operation—this is the duration of the external microelements of machine setup.

Phase 2: Transformation of internal microelements into external ones

The moderator moved (in agreement with team members) the green stickers (external microelements) either to column 1 (starting activities) or to column 5 (completion activities) (Table 5).

Phase 3: Improvements of internal and external microelements

After the separation of internal and external microelements of machine setup, the team made some suggestions for improvements of internal and external microelements.

The results of the creativity workshop are presented in Table 6.

Table 5. Analytical card of transformation of internal into external microelements of jet-machine setup

ANALYTICAL CARD – conversion of microelements						
Machine setup element	EXTERNAL ELEMENTS ■	INTERNAL ELEMENTS ■			EXTERNAL ELEMENTS ■	TOTAL TIME [min]
	1. Starting activities	2. Tool dismantling procedure	3. Tool mounting procedure	4. Start of the machine	5. Completion activities	
Element duration [min]	73.0	12.4	24.67	6.7	3.2	119.97
MICROELEMENTS	Machine shutdown 31 sec X	← ●	Fixing the crane clamps 69 sec X	Test of the jet operation 117 sec X		
		Manipulator setup 41 sec X	Insertion of a new tool 29 sec X	Synchronization of jet-machine 166 sec X		
	Walk to the office 14 sec X	← ●	Centering the tool position 164 sec X	Confirmation of the first samples 81 sec E		
	Entering the data into the documentation 385/2=192 sec X	Lifting the previous tool from the machine 89 sec E	● ●		Entering the data into the documentation 385/2=192 sec X	
	Tool heating 3811 sec X	← ●				
			Spraying the cylinder 72 sec E			
DURATION OF INTERNAL ELEMENTS [min]	0.00	12.40	24.67	6.70	0.00	43.77
DURATION OF EXTERNAL ELEMENTS [min]	73.00	0.00	0.00	0.00	3.20	76.20

Table 6. Analytical card of improvements to internal and external microelements of jet-machine setup

ANALYTICAL CARD – IMPROVEMENTS						
Machine setup element	EXTERNAL ELEMENTS 	INTERNAL ELEMENTS 			EXTERNAL ELEMENTS 	TOTAL TIME [min]
	1. Starting activities	2. Tool dismantling procedure	3. Tool mounting procedure	4. Start of the machine	5. Completion activities	
Element duration [min]	73.00	12.4	24.67	6.7	3.2	119.97
MICROELEMENTS	Machine shutdown 31 sec X 		Fixing the crane clamps 69 sec X 	Test of the jet operation 117 sec X 		
		Manipulator setup 41 sec X 	Insertion of a new tool 29 sec X 	Synchronization of jet-machine 166 sec X 		
	Walk to the office 14 sec X 		Centering the tool position 164 sec X 	Potrditev prvih vzorcev 81 sec E		
	Entering the data into the documentation 385/2=192 sec X 	Lifting the previous tool from the machine 89 sec E 	 		Entering the data into the documentation 385/2=192 sec X 	
	Tool heating 3811 sec X 					
			Spraying the cylinder 72 sec E 			
DURATION OF INTERNAL ELEMENTS [min]	0.00	12.40	24.67	6.70	0.00	43.77
DURATION OF EXTERNAL ELEMENTS [min]	73.00	0.00	0.00	0.00	3.20	76.20
SUGGESTIONS FOR IMPROVEMENTS	Documentation is obtained during walk to the machine - 190 sec	Reduction of walk time by optimization of walking path - 24 sec	No searching of key – key is always on a fixed position - 50 sec			
	Reduction of walk time by optimization of walking path - 30 sec	Faster water discharge - 12 sec	Reduction of walk time by optimization of walking path - 25 sec			
	Tool preheating before mounting on the machine – executed parallelly - 0 sec		Container for the granulate should be placed to a fixed position - 39 sec			
SAVING [min]	-3.66	-0.60	-1.90			-6.16
NEW TIMES [min]	69.34	11.80	22.77	6.70	3.20	113.01

The results of the first SMED workshop were:

- a reduction of internal microelements of machine setup time from 119.97 minutes to 43.77 minutes (a reduction of 63.5%),
- a reduction of the total machine setup time of 6.16 minutes.

The largest reduction of machine setup

time was achieved by moving the microelement "Tool heating" from being an internal element "3. Tool mounting" to an external element "1. Starting activities" with an anticipated time of 64 minutes.

Pre-heating of the tool at the pre-heating station (Fig. 9) allows the tool to be heated to the

operating temperature before mounting. Thus, heating in the machine is not necessary.

Sketch of the pre-heating station

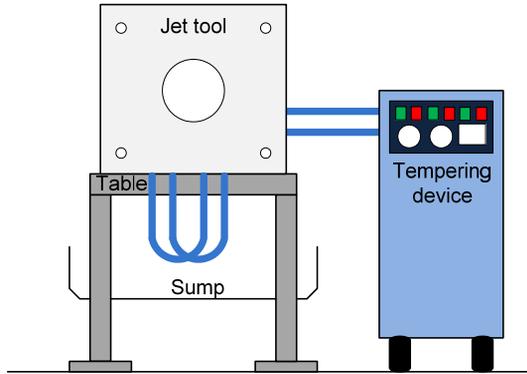


Fig. 9. Pre-heating station

The team calculated the time required for the return of investment in the pre-heating station:

$$t_I = \frac{A_I \cdot 60}{C \cdot t \cdot N}, \quad (2)$$

where:

- t_I time for return of investment [weeks]
- A_I invested amount [€]
- C cost of machine downtime per hour [€]
- t saved time due to tool pre-heating [min/changeover]
- N number of tool changeovers per week [changeovers/week].

The pre-heating station costs about € 9000. It is estimated that the tool is changed 12 times per week. The cost of jet-machine waiting-time is 54 €/h. The time saved due to tool pre-heating is 63.5 min/changeover. The return of investment in the pre-heating station is:

$$t = \frac{9000 \cdot 60}{54 \cdot 63.5 \cdot 12} = 13.1 \text{ weeks.}$$

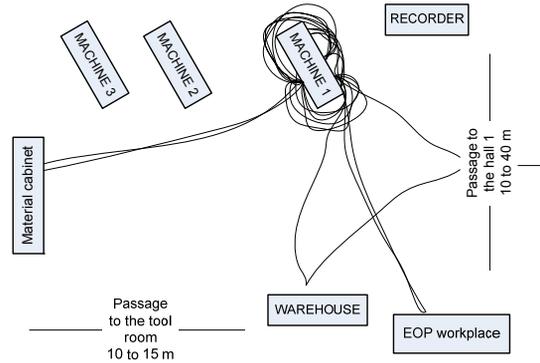


Fig. 10. List of new paths for the setup operator

The team organized a creativity workshop in order to eliminate unnecessary paths for the setup operator. The results of the creativity workshop are presented in Fig. 10.

Table 7. Operating instructions for jet-machine setup

Machine KM 800		OPERATING INSTRUCTIONS	
No.	MICROELEMENTS	Pay attention to:	Figure:
1	Read operating instructions		
2	Check if the new tool is ready		
:	:	:	
15	Setup of new tool handle		
16	Machine shutdown		
17	Program loading		
:	:	:	
42	Control of products	Control dept. participates	
43	Packing of personal tools		
44	Packing of vacuum cleaner		
:	:	:	
47	Packing of documentation		

Phase 4: Standardization of microelements

The team also carried out a standardization of internal and external microelements and entered the results on the form "Operating instructions for jet-machine setup" (Table 7).

The new operating instructions had to be tested, so the day after the first SMED workshop the setup operator carried out machine setup according to the new operating instructions and completed internal microelements within 39 minutes, which is an additional improvement of 4.77 minutes.

Step 7: REPEATED ANALYSIS OF MICROELEMENTS

The target setup time defined in step 2 was not achieved, so the team decided to repeat the analysis of machine setup microelements.

Before the second SMED workshop, the team leader organized a creativity workshop in order to obtain suggestions for improvements, the realization of which would additionally reduce setup time.

The creativity workshop indicated that setup time could be significantly reduced if the following improvements were made:

- introduction of fast hydraulic chuck-and-center system for tool fixing,
- introduction of fast hydraulic multi-joints.

3 CONCLUSION

The manufacturing management decided that the KM 800 jet-machine setup time should be reduced. They selected team members to carry out a SMED workshop with the goal of reducing the setup time. The target value was a reduction of 50%.

The team first documented the elements of the existing jet-machine setup, recorded microelement setup times, drew the path made by the setup operator, took photos of setup details and filmed the whole setup procedure with a video camera.

An analysis of setup microelements was then made, which indicated that some internal microelements could be transformed into external ones.

The team leader organized a creativity workshop, the goal of which was to make improvements to internal and external microelements. The creativity workshop yielded

two suggestions for improvements that should significantly reduce the setup time.

The SMED workshop on the reduction of jet-machine setup time will be repeated until the goal has been achieved: a setup time shorter than 10 minutes [14].

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