Practical verification of a logistic Lean model for small enterprises operating in Poland

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Abstract. The paper presents a Lean model designed for purposes of internal logistic and transport processes and elaborates upon its influence on the effectiveness of these processes. The paper also discusses results and conclusions of practical model verification using the Siemens Plant Simulation software. The final section provides recommendations for further actions and describes the key problems arising from the model implementation. The study has been limited to a single small-size plant, representative of the Polish metal-mechanical sector of industry, as well as to results of verification of the proposed Lean model by computer simulation without its practical implementation at any production line. The Lean model implementation has been limited to the internal transport and logistics process for groups of similar parts. Verification of the Lean model elements has been limited by capabilities of the software used. Some of the model elements could only be verified through their actual application under production conditions. A description of methodology for implementation of the Lean model that could be adapted to requirements of other companies representing the Polish metal-mechanical industry.

1. Lean and small enterprises in Poland – literature review

Having performed a literature review, the authors believe that there are no studies discussing Lean methods and tools which are used in small enterprises in Poland. This is a direct consequence of the absence of a Lean model that would enable them to be effectively implemented. One can also notice the lack of publications addressing the relationship between the Lean assumptions and the processes of logistics and transport performed in Polish small enterprises. This has led the authors to a decision on making this problem the foundation of their scientific and research endeavours. One may presume that the capacity to implement selected Lean concepts in logistic and transport processes should be typical not only to large but also small enterprises. By improving good practices of the Lean implementation in logistic and transport processes of large businesses, one can also develop Lean principles pertaining to this sphere, yet applicable to small companies, so that the logistic and transport efficiency can also be raised in small enterprises.

The literature review has led to the following conclusions:

– Many authors, including Bednarek [1], Ford [6], Harris [7], Imai [8], Jacyna [9], Rother [10] and Taichi [11] concentrate on managerial problems of large businesses, where classical structures and processes can be identified;
– Authors such as Blaik [2], Brajer-Marczak [3], Czerska [4], Dubiel [5] and Harris [7] have confirmed that the literature of the subject does not present any methods to apply the Lean tools and models in small enterprises in Poland, which makes the efforts aimed at improving the efficiency of their logistic and internal transport systems significantly more difficult.
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2. Lean model for small enterprises

The main characteristic feature of the Lean model, as illustrated in Figure 1, is that it can be applied to all internal processes of logistic and transport nature in small enterprises in Poland. The internal transport process is a combination of all actions performed starting from receipt of materials until shipment of finished products. They can either be performed by the company's own resources, or outsourced. However, the most important aspects are suitable work organisation, qualifications of employees handling individual processes as well as characteristics of internal transport, such as the maximum running speed that would not compromise safety and quality of the goods transported, short loading and unloading times, short transport routes, use of adequate means of transport, elimination of overloading and reduction of volumes being trans-shipped.

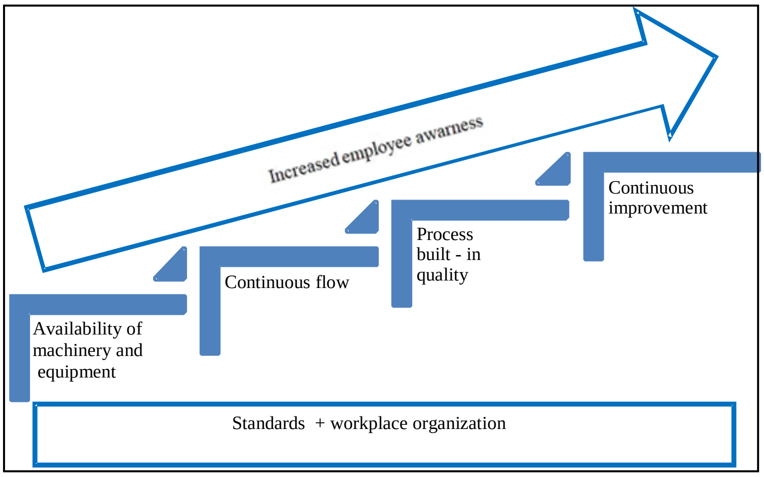


Fig. 1. Lean model of internal logistic and transport processes proposed for small enterprises in Poland.

3. Components of the model

The Lean model proposed by the authors consists of 6 components, as described below along with the methods and tools that comprise them.

Standards and workplace organisation

Standards come as a fundamental component of the model, and their implementation ensures that value can be added in the process. The component referred to as "standards and workplace organisation" is mainly used to introduce self-discipline and to ensure that all employees comply. In order to facilitate it, one can use some visual elements, like colourful containers for parts or colour codes to mark transport routes.

Deploying the "standards and workplace organisation" component is based on several methods, visualisation being one of them, as it should make work easier to employees and help outsiders understand it properly. Principles/standards should be formulated in a manner ensuring that one can notice any deviations and apply corrective measures as well as identify and eliminate all irrelevant and insubstantial warehousing and transport activities.

Continuous flow

The "continuous flow" component of the Lean model puts the emphasis on the fact that the production process should depend on the orders placed by the customer. Goods handling and transport requires application of one-piece-flow, which makes it possible to increase flexibility of production control, reduce the number of workers involved, eliminate product defects and identify points of disruption.

The purpose behind application of the "continuous flow" component is to reduce the time of individual production processes, to improve quality and flexibility in processing of the customer's orders as well as to reduce stock levels.

The main premise underpinning the "continuous flow" component of the Lean model is to perform tasks and production exclusively related to the product which is currently necessary for and expected by the customer, and to attain production flexibility by reducing changeover times and increasing the frequency of transport of finished and semi-finished goods.

Process built-in quality

What matters greatly to the pre-assumed quality is the machinery and equipment at hand. All pieces of equipment involved in logistic and transport processes must operate at their optimum. If they have any defects, the scope of their application may be insufficient and encumbered with errors. Machines that perform all transport processes in an appropriate manner condition the quality and do not require continuous supervision and inspection.

The main premises behind the implementation of the "process built-in quality" component include non-acceptance of defective or damaged parts, identification and elimination of the latter, as well as manufacture of individual products with sufficient quality and handing them over to the subsequent work station or logistic process.

Availability of machinery and equipment

The Lean model component referred to as "availability of machinery and equipment" is inextricably linked with the premises behind TPM (Total Productive Maintenance). It exerts a direct impact on how logistic and transport processes function. Every stoppage of a piece of transport equipment makes the order lead time longer, consequently causing a failure to fulfil customer requirements.

The main assumptions underpinning the “availability of machinery and equipment” component of the Lean model proposed are that machinery and equipment should work flawlessly and that they should be serviced by the personnel in a way to prevent defects. It is therefore necessary to appoint a person held accountable for all activities related to operation, changeover and maintenance of equipment. This makes it possible to maintain transparency and stability of the production process. Moreover, a machine that is available equals on-time transport to the customer or transfer to another production process.

In order to effectively implement this component, one needs the following:

- Autonomous service personnel when expanding the scope of employee responsibility by introducing principles of preventive maintenance of equipment to support the execution of logistic processes;
- Application of the SMED method in order to analyse and reduce the time of preparatory and finalising activities, i.e. the changeovers performed by workers in logistic and transport operations.

Informed employees

One of the purposes of the Lean model proposed is to increase the business’s transport effectiveness. The difference between a traditionally managed enterprise and one which is managed in line with the Lean principles is in the understanding of the nature of the production process and the resulting conduct of employees as well as their involvement and skills. These are the factors that exert the highest influence on the company’s success.

The “informed employees” component is based on an assumption that one truly listens to the employees’ voice and responds to their remarks, and that insights concerning the production process and its individual steps are shared. Consequently, one should consider such characteristics as team work capabilities, perceiving changes to the process as improvement opportunities, positive attitude towards the objectives defined or flexibility at work as those of key importance.

The “informed employees” component of the Lean model proposed is implemented by means of a system of suggestions, i.e. by enabling people to submit streamlining concepts with regard to how individual processes function, as well as to work in teams and solve problems, being involved in a collective analysis of disruptions, performed by collaborating organisational units.

4. Selection of enterprises for verification purposes

For purposes of practical verification of the Lean model in question, a small enterprise operating in the processing industry has been selected. The choice has been made by taking into account the goods they produce, their customers, the specifics of production processes as well as the logistic and transport processes they perform. The plant subject to the study manufactures black steel and copper elements, such as pipes, leads, closed sections and fasteners in a wide range of diameters. The company attaches much attention to the quality of products, which has been confirmed by the ISO 9001 and ISO 14001 certificates they held. They deliver products to a broad range of customers, from individual recipients to large businesses, for whom they are among key suppliers. They supply companies producing clothes, food, paper and derivative products, chemicals, automotive vehicles, furniture, machinery and equipment as well as telecom components.

The enterprise may be regarded as representative of small business entities operating in Poland. The company:

- employs 50 persons,
- uses quality management systems certified for compliance with ISO 9001:2015 and ISO 14001,
- delivers to very diversified recipients of their products,
- runs typical logistic and transport processes equivalent to those which other small and medium-size enterprises perform.

5. Practical verification of the Lean model

Simulation plan

In order to conduct the simulation, it was first necessary to define its assumptions and to plan it. The plan of the Lean model verification procedure has been illustrated in Figure 2. The figure shows the sequence on individual actions.

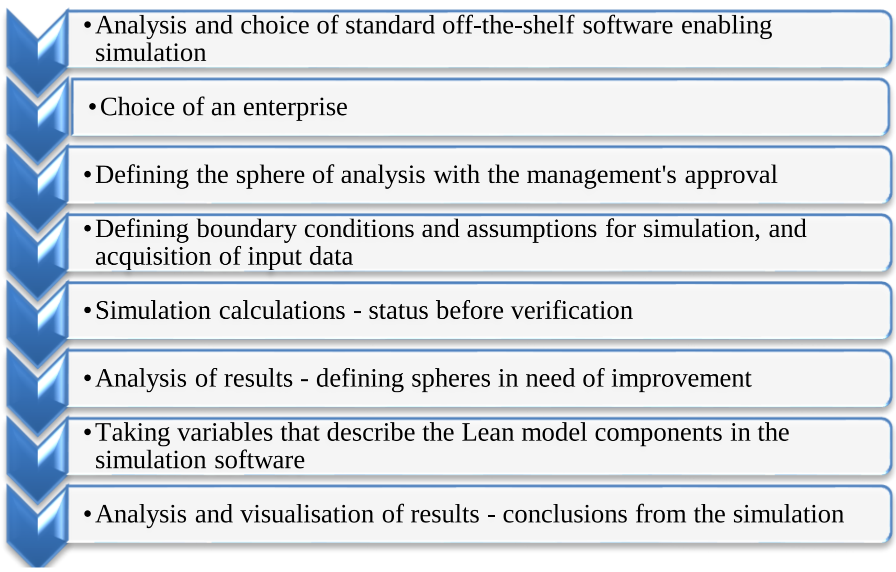


Fig. 2. Plan of the Lean model verification procedure for a small enterprise.

The manner in which simulation calculations were conducted has been illustrated in Figure 3. Real-life data characterising individual shop floor (Gemba) processes were collected in the first instance. Thus obtained, the partial data made it possible to run calculations required for simulation of the actual production process. Next, the standards (the pattern) that selected processes should meet under the Lean conditions were defined. Application of these standards was intended to gradually lead to an increase in efficiency of logistic and transport processes. Once the threshold values, hypothetically attainable after the Lean improvements, as well as the outcomes (standards) were defined, the authors computed real-life results of efficiency improvement and compared them with the potential effects expected to be obtained as a result of the Lean implementation. The elaboration was completed by drawing conclusions.

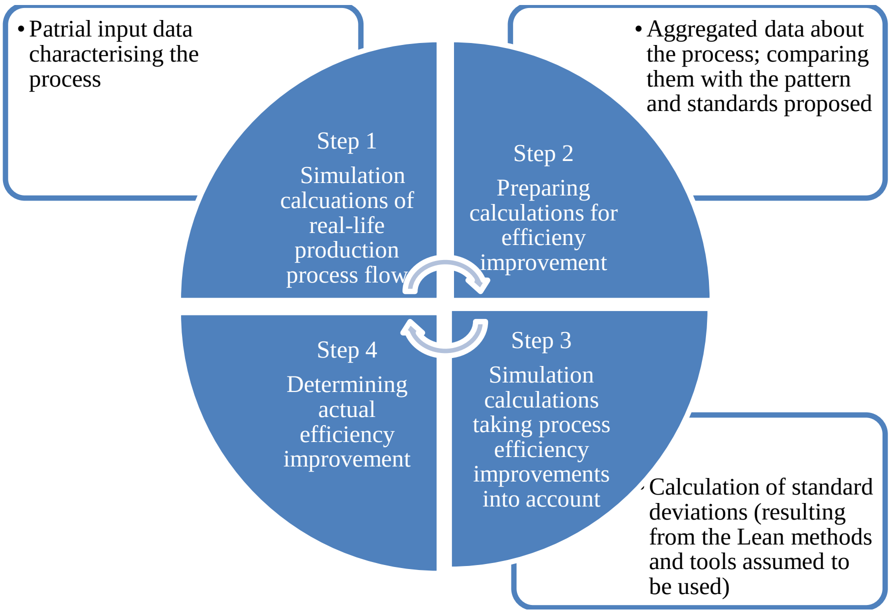


Fig. 3. Procedure of simulation calculations.

6. Assumptions, boundary conditions and goals of simulation

What proved necessary for purposes of the simulation was to define its boundary conditions. The authors set the expected level of efficiency (pattern following the Lean implementation) for the operation of machinery and equipment, stock levels, changeover times as well as malfunction rate and timeliness of customer order processing.

The authors had assumed that, once the improvements proposed were introduced, efficiency would rise at individual workstations. Also the malfunction rate and the share of transport in total working time was expected to drop. The simulation made it possible to verify if one can obtain model effects following the implementation of the Lean concepts, such as the following:

- Availability increase by 15-20%;
- Productivity increase to 50%;
- Reduction of the share of time of transport-related activities at individual workstations by at least 10%.

7. Improvements deployed

As a part of the practical verification, the authors undertook a number of actions resulting from the assumptions of the Lean model proposed. The scope of their efforts was based on simulation calculations as well as experiments undertaken all over the premises of the company studied. The detailed data acquired in this process have been provided and discussed below.

Availability of machinery and equipment

Figure 4 illustrates the manner in which calculations involved in the Lean model verification were conducted for the "availability of machinery and equipment" component.

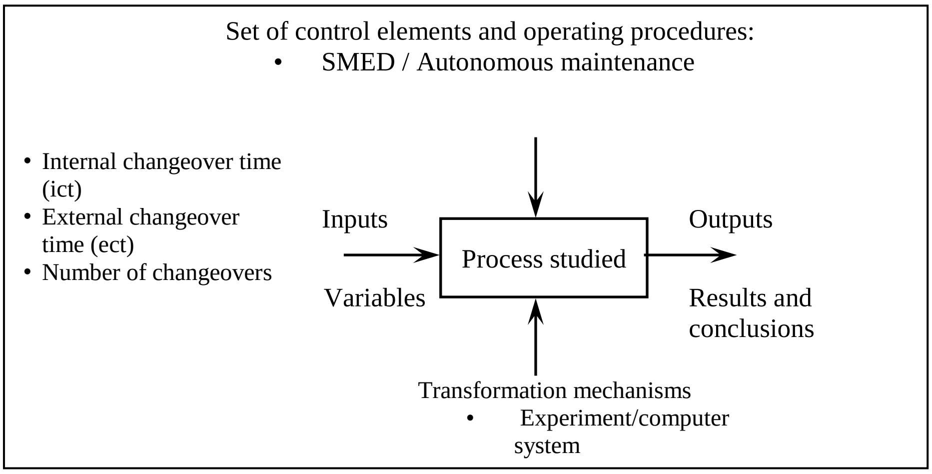


Fig. 4. Verification of the model for the "availability of machinery and equipment" component. Authors' own materials based on [10].

In order to calculate the availability of machinery and equipment, the SMED principles were experimentally implemented at workstations. Both a training workshop and an analysis of the outcomes thus obtained were performed (compare Table 1). Following the Lean principles, a number of changes were introduced to improve efficiency of transport operations. Results of the redesigned system of handling and transport between individual workstations have been collated in the Table 2 below. It illustrates the efficiency of workstations both before and after the deployment of improvements.

Table 1. SMED analysis – status before and after verification.

Part number	Operation description	Operation type	Type of changeover before and after verification	
			BEFORE	**AFTER**

	Workpiece transport to machine	transport	internal	external
	Documentation analysis	changeover	internal	external
	Preparing tools for machine	changeover	internal	internal
	Working head picking	changeover	internal	internal
1097	Working head replacement	changeover	internal	internal
	Parameter setting	other	internal	internal
	1 piece verification	work	internal	internal
	Putting tools aside	changeover	internal	internal
	Placing/transporting finished workpiece in/to container	transport	internal	external

Another step in the experiment was to implement the autonomous maintenance procedure. Maintenance cards were introduced, and daily inspection of key machine and equipment components made it possible to minimise the frequency of malfunctions. Furthermore, a workgroup was established and commissioned to analyse the reasons for the faults still encountered, to schedule inspections and to run maintenance of machines and equipment in coordination with operators and supervisors of individual areas.

Continuous flow

Figure 5 illustrates the workflow of verification of the continuous flow component.

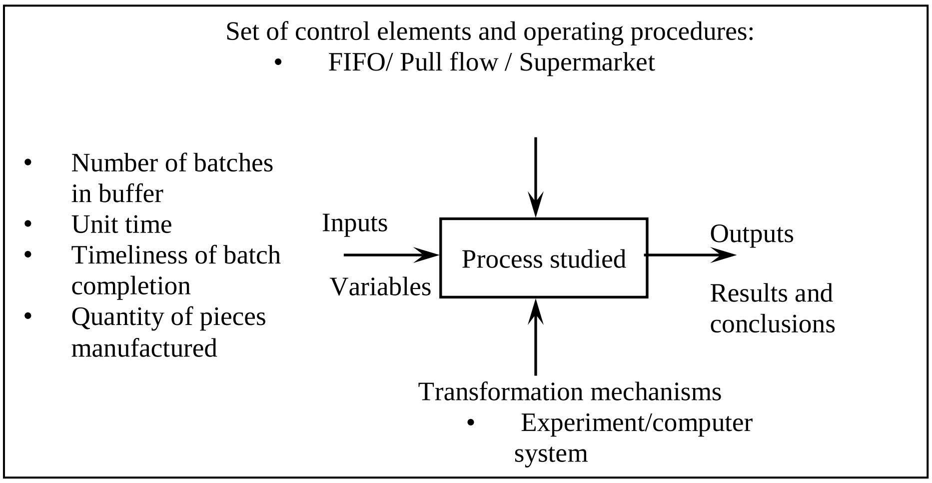


Fig. 5. Model verification for the "continuous flow" component.
Authors' own materials based on [10].

In order to verify the continuous flow (i.e. the ability to obtain stable flow while simultaneously reducing the stock in progress), the FIFO (First In, First Out) principle was applied for product flow control purposes at every workstation examined. In collaboration with employees, a supermarket of finished goods was designed and implemented, with a specific stock level pre-defined for individual products. Thus the probability of untimely completion of jobs was reduced and stocks in progress were minimised. This solution enabled implementation of the pull system and confirmed the reduction of batches remaining in intermediate storage areas (compare Figure 6).

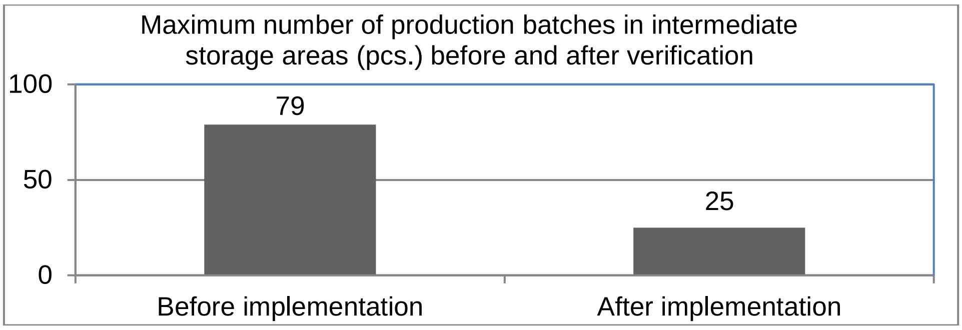


Fig. 6. Maximum number of production batches in an intermediate storage area before and after verification.

8. Simulation results and conclusions

The practical verification of the Lean model enabled successful calculations and made it possible to develop a graphical model of the process subject to the study before proceeding with further steps of verification. The simulation software used in the follow-up brought results which confirmed that the assumed procedure of computational and experimental verification – or more generally, the implemented Lean model – successfully increased the efficiency of the chosen logistic and transport processes. It was confirmed by the results presented in the following tables and figures:

- availability/efficiency of workstations tested (Table 2),
- percentage share of transport related activities in total available working time (Table 3),
- quantity of parts produced and production timeliness (Figure 7),
- utilisation of workstations over the entire available time (Figure 8 and 9).

Table 2. Availability and efficiency of workstations before and after verification.

Workstation	Availability and efficiency before and after verification		Trend
	BEFORE	**AFTER**	

Workstation 1 – saw	9.8%	27.5%	**+17.7%**
Workstation 2 – bending machine	43.5%	88%	**+44.5%**
Workstation 3 – welding	15.5%	33.5%	**+18%**
Workstation 4 – machining	17.5%	34.5%	**+17%**
Workstation 5 – finishing	6%	12%	**+6%**

Table 3. Percentage share of time of transport related activities in total available working time before and after verification.

Workstation	**% share of transport related activities before and after verification**		**Trend**
	BEFORE	**AFTER**	
Workstation 1 – saw	76%	62%	**-14%**
Workstation 2 – bending machine	32%	0.37%	**-31.6%**
Workstation 3 – welding	74%	60%	**-14%**
Workstation 4 – machining	69%	59%	**-10%**
Workstation 5 – finishing	81%	81%	**0%**

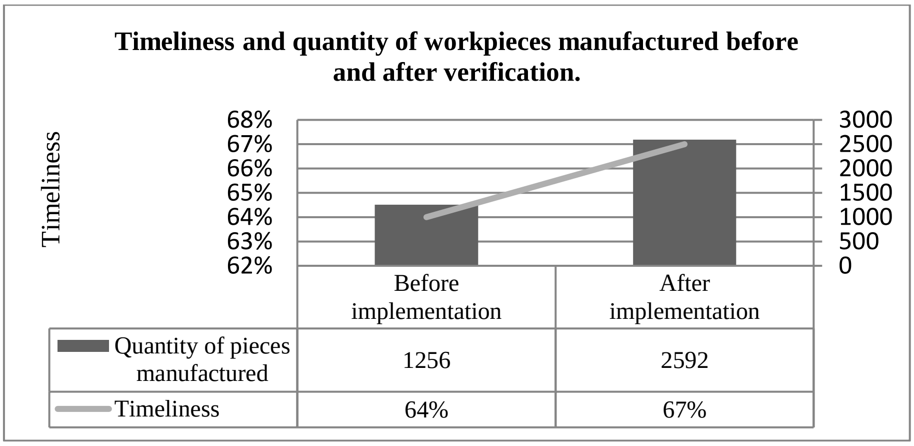
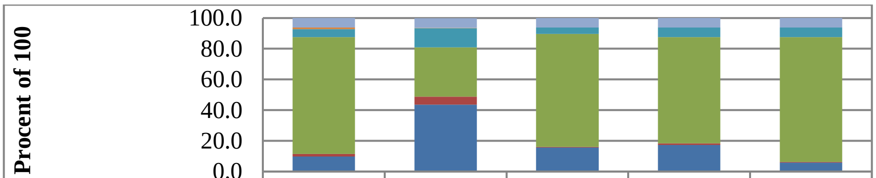


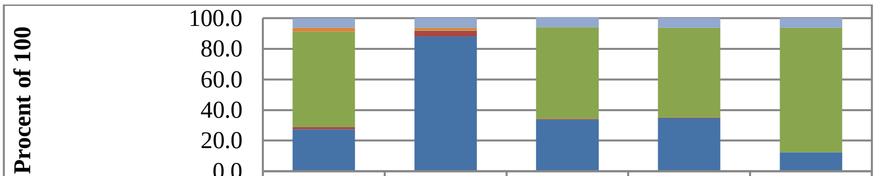
Fig. 7. Timeliness and quantity of workpieces manufactured before and after verification.

Figures 8 and 9 illustrate data concerning the utilisation of workstations. Having compared them, one can notice that the outcomes of the Lean model development work included successfully increased availability of workstations and transport equipment. On the other hand, the malfunction rate and the waiting time were reduced. Following the deployment of improvements, one should particularly mind, for instance, the bending machine station which started being utilised in nearly 100%, while the share of effective work performed at other stations increased nearly twice. The data commented upon imply that the bending machine station should be subject to special attention of adequate services in the future. This is where the most complex and time-consuming processes are handled, affecting efficiency of other production areas.



	Saw	Bending machine	Welding	Machining	Finishing
Pause	6.3	6.3	6.3	6.3	6.3
Maintenance	1.0	0.2	0.0	0.0	0.0
Malfunctions	5.2	12.5	4.2	6.3	6.3
Blocking	0.0	0.0	0.0	0.0	0.0
Waiting/Transport	76.0	32.1	73.6	69.2	81.2
Changeover	1.8	5.3	0.4	1.1	0.4
Operation	9.8	43.5	15.6	17.3	6.0

Fig. 8. Workstation utilisation **BEFORE** full verification of the Lean model.



	Saw	Bending machine	Welding	Machining	Finishing
Pause	6.3	6.3	6.3	6.3	6.3
Maintenance	2.6	1.6	0.0	0.0	0.0
Malfunctions	0.0	0.0	0.0	0.0	0.0
Blocking	0.0	0.0	0.0	0.0	0.0
Waiting/Transport	62.3	0.4	60.1	58.6	81.5
Changeover	1.3	3.7	0.4	0.5	0.0
Operation	27.5	88.1	33.6	34.7	12.3

Fig. 9. Workstation utilisation **AFTER** full verification of the Lean model.

The aforementioned verifications and experiments proved that the proposed Lean model enabled an increase in efficiency of individual workstations, and particularly of the transport and logistic ones. The foregoing included:

– Availability/efficiency increase at individual workstations (see Table 2);
– Increased quantity of items produced and timeliness of manufacture (see Figure 7);
– Transport activities converted under the experiments (SMED workshop) into “external” activities, thus increasing the availability of individual workstations (see Table 1);
– Variables introduced to describe the “availability of machinery and equipment” component of the model proposed, which consequently enabled reduction of the share of malfunctions in the total working time of individual workstations (see Figure 8 and 9).

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