An Application of the SMED Methodology in an Electric Power Controls Company

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Abstract

Lean production is a strategy for high competiveness in manufacturing. The capability for economical manufacturing small batch sizes is an essential requirement for achieving lean production. This facilitates mixed production of several kinds of products to match varying product demand and can have a major impact in reducing inventories. An obvious requirement for this is the high frequency of equipment setups or product changeovers. This will not be attractive unless set-up times and costs can be reduced to competitive levels. The application of SMED can achieve this. SMED is a well-established methodology involving a set of techniques, methods and guidelines to achieve fast product changeovers at machines. This paper describes the application of SMED in the production process of plastic and metal components required for the assembly of several types of circuit breakers. The work was carried out during a short period of a few months under a master thesis project. Several important SMED strategies and solutions were implemented and evaluated in terms of their impact on productivity and on other manufacturing performance measures. Three specific machines were involved: a punch-bending machine, a punch press and an injection moulding machine. An important contribution was made by introducing innovative and simple solutions such as adapting tools and normalizing changeover operations. Most of the achieved results exceeded the initial expectations. Beyond the purely technical and economic benefits of SMED, better workstations' ergonomic conditions were also attained. Besides the usual quantification of setup time reduction, other indicators were calculated, namely: work-in-process (WIP), annual setup cost and distance travelled by operators during the changeover process. Reductions of setup time varying from 59% to 90% were achieved. WIP of metal components was reduced from 17.05 to 7.74 days reducing more than 50% on the corresponding costs. A more impressive reduction on WIP was obtained for plastic parts, actually from 5 to 1.09 days of work corresponding to a WIP cost reduction of over 80%. The distance travelled by operators during the changeover process was dramatically reduced too: typically a reduction from 300 m to 10 m and less. The total annual cost savings projection, in this small area of parts production, is near 20,000 €. Although large benefits were obtained from the study, scope for further improvement still exists. In fact the objective of product changeover times below 10 minutes aimed by SMED was not achieved in one case.

Keywords

Machine setup, Quick changeover, SMED, Mass customization, Lean manufacturing.

Introduction

It becomes increasingly evident and is generally accepted that mass production, which has dominated the industry for a long period, in the last century, has become obsolete [1]. More than ever, companies must be able to manufactured large variety of products, in small quantities, in order to respond to market requirements[2]. However production costs must be competitive, otherwise accompany may not be able to subsist in the current economic markets within the global competition paradigm of today. Well known new manufacturing paradigms, namely lean and agile manufacturing, emerged to cope with the challenges of competition within the new market paradigm. Among other aspects, it is obvious that the necessary time to change production from one product to another, commonly referred as product changeover time, must be kept as short as possible for allowing manufacturing in very small quantities of a great variety of products at competitive production costs. This is the purpose of the SMED methodology, one important tool initially though for lean manufacturing but of great value to agile manufacturing. SMED aims to substantially reducing product changeover time towards achieving single digit time values, i.e., less than 10 minutes.

The main objective of this paper is to describe an industrial application and implementation of the SMED methodology in a company of electric power controls, more specific all within a production process of plastic and metal components involving three machines: a punch-bending machine, a punch press and an injection moulding machine. Besides the usual measurement of the setup time reduction, a clear objective of this work is the quantification of other indicators, such as: work-in-process (WIP), annual setup cost and distance travelled by operators during the changeover process. The annual setup cost is of particular importance for the company administration.

The structure of the paper is as follows. After this introduction, the second section provides some fundamentals on lean production and SMED. The third section describes the industrial application of SMED in the electric power controls company. The main results of the implementation are presented and discussed on the fourth section. On the last section some concluding remarks are outlined.

Fundamentals of Lean Manufacturing and SMED

Lean manufacturing[3, 4]is the western designation for TPS - Toyota Production System [5, 6, 7] mostly developed at Toyota Motor Company after the Second World War [8]. It is considered a systematic approach specially focused on the identification and elimination of waste, also known as "muda", along the value added chain of a product. Waste is considered any activity or event that does not add value to the product. Ohno[5] identifies seven types of waste: overproduction (in terms of earliness and/or excessive quantity), defects, inventory, transport (of materials), movement (of people), over-processing (or inadequate processing) and waiting. The expression "less is more" represents the idea of the Japanese production philosophy, meaning wasting less time, using less production area, as well as less material and human resources, without compromising the products' quality, cost and delivery [9].

With today's pressure for reducing non-adding value activities, which means to implement lean manufacturing philosophy, improving performance acting upon products' changeover activities is becoming more and more important [10]. As previously referred, the type of demand that characterizes current markets requires supplying small quantities of a great variety of products, likely demanding a great number of changeovers. So, frequent product changes and short product changeovers become key requirements to achieve success [11, 12].

SMED is a methodology put forward by Shingo [7] focused on achieving very quick production changeovers of products. The methodology is supported by a set of techniques, methods and guidelines. A changeover is a production set-up activity extended over the time interval between the production of the last good part in a given batch and the first good part of the following batch, and, typically, involves preparation of equipment and tools, setups, running of trial parts and adjustments [13]. Changeover costs can be tangible or intangible. The first can be expressed in monetary units while the second cannot [16]. Yang and Deane [17] identify the following tangible costs: lost production, lost capacity, inventory, labour, trial parts and defects. Intangible costs include the costs inherent to: response time to client, risk of market share loss, and, operators and equipment stress.

According to Sekine and Arai[11], the efficiency of changeover is determined by three key elements: (i) knowledge about the technical aspects of equipment and tools, (ii) work organization (who does what and when), and, (iii) knowledge about the method (how to do). An important requirement for the SMED success is operators' motivation for collaborating and accepting new working practices and methods. In fact, even with equipment designed for quick setups and an adequate work organization, efficient and effective changeovers cannot be achieved if the operators do not cooperate and recognize inherent advantages of new changeover processes [14]. It is also recognized that many organizations do not take into account changeover costs, being therefore unable to identify profits associated to the changeover time reduction [15].This fact may constitute a serious obstacle to SMED studies and implementations.

SMED classifies the changeover operations in two types: internal operations, which can only be executed if the equipment is stopped, and external operations, which can be executed while the equipment is running. The methodology comprehends three stages: (i) separation of internal and external operations, (ii) conversion of internal operations into external operations (whenever possible), and, (iii) rationalization of operations. Stage (i) is considered the most important [18], and can lead to a changeover time reduction of 30 to 50% [19]. In fact, in many changeover processes observed in the industry, it is common to identify operations that are performed when the equipment is stopped that could be executed with the machine running [20]. In stage (ii) the internal operations are thoroughly analysed towards converting them into external ones whenever possible. The third and last stage is the rationalization of all the operations (both internal and external) to make them more efficient [18]. Standardization of dimensional aspects is one of the issues frequently addressed in changeover processes. Figure 1 demonstrate the use of shims attached to dies to obtain both a standard clamping height (80mm) and a standard die height (320mm).

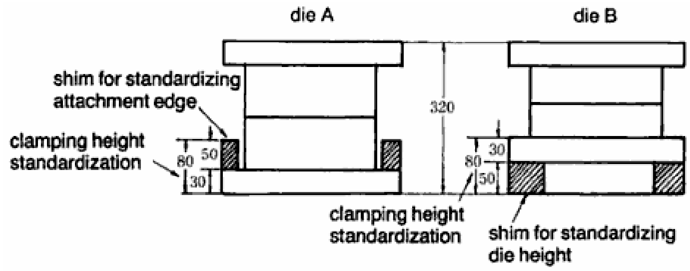


Figure 1: Standardized height of die and clamping [7]

The correct placement or positioning of parts and the setup of tools or dies in a machine can be a difficult and time consuming task that may involve a number of adjustments. To overcome difficulties, novel solutions, that allow quick setup and adjustments, have been developed. One commonly used in SMED solutions is a pair of cenetring jigs applied as illustrated in Figure 2, thus eliminating the need for adjustments.

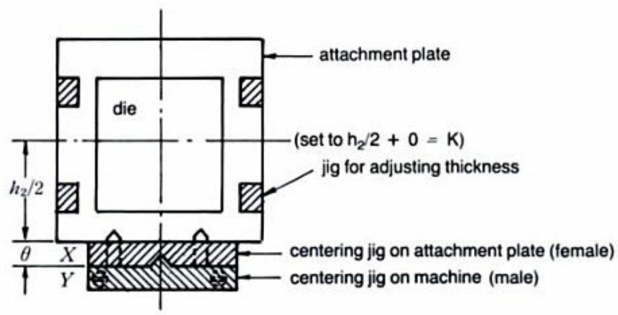


Figure 2: Centring jigs [7]

The cases represented in Figures 1 and 2 are two examples of typical solutions frequently used in SMED studies that can dramatically reduce the changeover times of dies. Other practical techniques may include the use of functional clamps, improvement of parts/tools storage and transportation and automation [21]. It should also be pointed up the important impact of implementing parallel operations. Parallel operations are different operations of the same changeover process carried out simultaneously by different operators. This is a strategy that can bring about considerable reduction in changeover time whenever it can be implemented. Details of these and other SMED novel ideas and solution can be found in Shingo's reference book [7].

SMED case studies

The SMED methodology has been studied and applied by academicians and people from industry. Many results and reports of this work can be found in the literature.

In the area of plastic moulding machines, the description of an industrial application of SMED was reported by Kays and Kara [22]. In this particular case, changeover teams were organized to collect data and perform a detailed analysis of the changeover process. Special attention has been given to the separation between internal and external operations, improvement of water connections and moulds' clamping, transport and storage. The main achievement was the reduction of changeover time from 365 to 73 minutes. Despite being quite far from the single digit time value aimed by SMED, the reduction was quite impressive enabling large reductions in product lead time at machines and also substantial increase in machine capacity and utilization.

Brian [23] describes an application case of the SMED methodology to punch presses relevant to the work here reported. A changeover time reduction from 30,4 to 9,68 minutes was attained. This improvement resulted in a reduction of the machines' non-productive time, which was used in favour of the client.

With a successful implementation of the SMED methodology several immediate benefits for the companies can be achieved. The first clear benefit is the reduction of unproductive time. This leads to production capacity and the productivity increase[17] and to better companies' capability to respond to changes in market demand [24].It is recognized that inventory levels are directly related to batch sizes which, in turn, are dependent on changeover times. Typically, large changeover times, lead to large batch sizes and small number of changeovers to avoid big losses on production capacity. Obviously, reduction of changeover times allows more frequent product changeovers. As a consequence batch sizes can be reduced substantially, the same happening to finish and WIP levels [19]. Additionally, as pointed out by Shingo [7], lower inventory levels allow: (i) increase of inventory turnover, (ii) improvement of the use of space area (less storage area), (iii) reduction of inventory handling and increase of productivity and (iv) elimination of safety inventory due to changeover mistakes variation of changeover time. With simple and efficient changeovers, errors are reduced and the trial tests when the machines restart can be avoided. Quality and safety improvements and reduction of processes' variability are important additional benefits expected from adequate SMED implementations [18].Particularly beneficial to companies' competitiveness is the substantial reduction in changeover costs, which include labour, equipment and opportunity costs [25].

SMED application at GE Power Controls Portugal

The main purpose of this work was the implementation of the SMED methodology at a power controls company in Portugal aiming at improving performance of metallic and plastic parts production and reducing inventory. Three specific machines were involved: a punch-bending machine, a punch press and an injection moulding machine.

In order to clearly understand the changeover processes, several changeover occurrences were observed. Video recordings were also made for detailed analysis and measuring of changeover times. It was clear that the changeover procedures were not efficient. In addition to high changeover times, high distances were travelled by operators to collect and look for dies, tooling and other auxiliary devices and documents. Moreover, there were a lack of changeover instructions and workstations' organization could clearly be improved. The same could be said to the organization and location of tooling and other elements associated to changeovers.

As WIP reduction in the area of metal and plastics parts was one of the company's priorities, in the context of the ongoing lean manufacturing improvement projects, the SMED project should strongly contribute to this. Thus the initial average values for this indicator were also measured. This was based on parts representing 80% of total production in the corresponding areas.

To allow the quantification of the monetary gains obtained after SMED implementation, the changeover costs (C_{CO}) associated to the initial scenario were determined. The tangible costs were calculated using Equation (1).

$$C_{CO} = C_{LP} + C_L + C_S + C_{ST} + C_M \qquad (1)$$

C_{LP} represents the lost production cost, C_L the labour cost, C_S the scrap cost, C_{ST} the inventory cost and, finally, C_M the machine cost. The annual changeover cost associated to each machine involved and the average annual savings per each minute of reduction in the changeover time was determined.

Another relevant aspect in the assessment of changeover efficiency is related tooperators' movements. In an organized and optimized changeover, an operator should move out of his working area during the changeover process as little as possible. Operators' movements were shown and measured using the so-called "spaghetti charts". Based on direct observation and analysis of video records, the travelled distances during changeover were estimate.

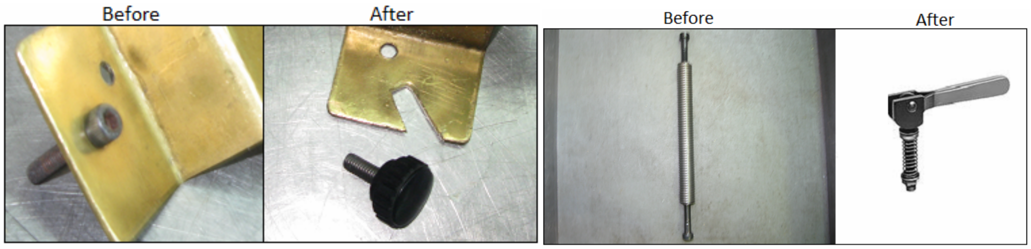
After the analysis of the initial scenario, the SMED methodology was applied. Special attention was given to operators' involvement. From this and mainly following some brainstorming sessions with the operators, quite a few ideas for improvement came up. Some of the solutions and proposals for improvement are described below.

- **Punch-bending machine**

In the punch-bending machine, internal and external operations were clearly separated. Looking for tools, cleaning and several parts' preassembling are now carried out while the machine is running, i.e. as external operations.

Some internal operations involving sliding units were converted into external ones. This was possible due to the existence of spare sliding units which are now set-up, i.e., assembled with bearings and cams, while machine are running.

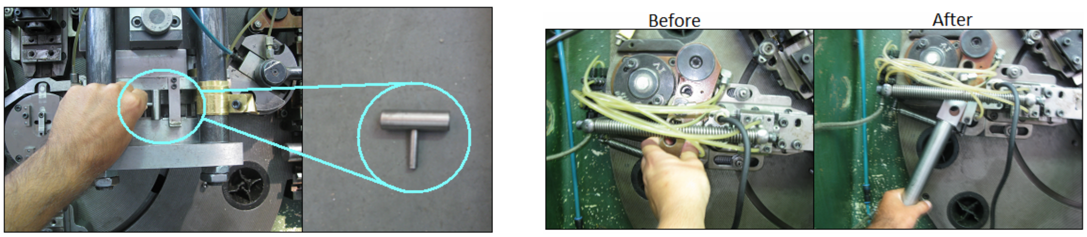
In terms of operations streamlining, most of the traditional screws were replaced by screws with knobs and, whenever possible, the holes were modified for easy setting (Figure 3(a)).In other cases screws were replaced by bell cranks (Figure 3(b)). Tools become unnecessary and the process of tightening/loosening much faster.



(a) (b)

Figure 3: (a) Use of screws with knob, (b) Application of bell cranks

The use of gauges was introduced to eliminate trial and error adjustments, as illustrated in Figure 4(a). To improve some operations, not only in terms of time spent but also regarding the ergonomic conditions, the use of levers was proposed and implemented (Figure 4(b)). Quick couplings were adopted for the hydraulic connections.



(a) (b)

Figure 4: (a) Application of gauges, (b) Use of levers

Dies exchange at the machines were aided by non-standard support plates(Figure 5). This approach delays dies exchange considerably.

Figure 5:Non-standard support plates for dies

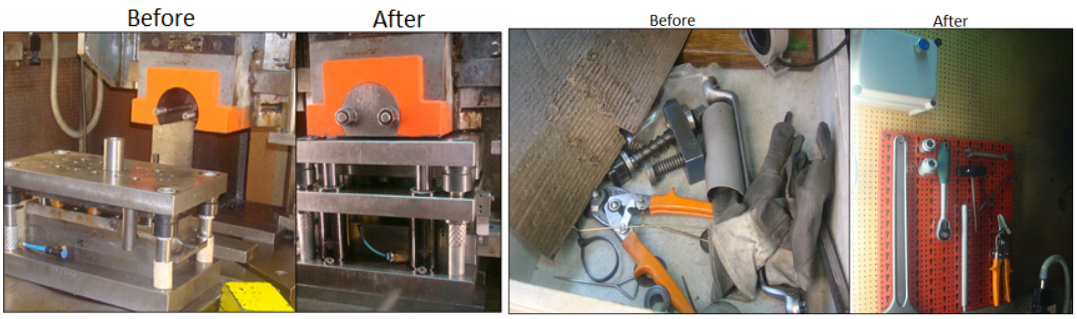
The standardization of support plates for dies was recognized as very suitable solution for substantial improvements in the changeover process and speeding up the exchange of dies. Due to this, a proposal for standardization of support plates was made to the company. This is currently being dealt with by the engineering department of the company.

Other improvements, including the introduction of parallel operation, were implemented in the changeover process of the punch-bending machine.

- **Punch press**

Following the SMED strategy for improving changeovers, as already done for the punch-bending machine, internal and external operations were identified for the changeover process of the punch press. In particular, a small support plate for a counting sensor was duplicated for allowing conversion of internal operations into external ones. When a single support was available this had to be removed from the die setup in the machine, with the machine stopped, and fixed in the new die, which would replace the former in the machine.

To streamline the changeover operations the height of dies was standardized, eliminating thus several adjustments, both in the press and in a raw material feeder. Additionally a poka-yoke system for centring the die in the press was implemented. This made the centring much faster since previously a micrometre was used to carry out the centring operation. Moreover, the application of hydraulic cylinders allowed a faster and easier opening/closing of dies, Figure 6(a). Figure 6(b) shows the use of a typical shadow board to organize the tools.



(a) (b)

Figure 6:(a) Use of hydraulic cylinders (b) Tools shadow board

Parallel operations were also implemented in the changeover processes of the punch press. This was possible for two main reasons. First, the changeover process operations could physically allow it; second because there were enough operators available to carry out the parallel operations strategy

- **Injection moulding machine**

In the injection moulding machine, like in the other machines, all preparatory work, for making ready the tooling and auxiliary set-up devices needed to quickly perform the changeover, is now executed while the machine is running. Additionally, two internal operations were converted into external ones. One of these operations required stopping the machine and removing the single available connector to be inserted in the next die to be changed. Thus, the first conversion was attained simply by manufacturing another connector (Figure 7) and inserting it, when needed, into the die to be used next. This assembly could then be done while the machine was running, i.e., as an external operation. The second conversion involved pre-heating of the die, which was previously performed inside the moulding machine and is now executed outside.

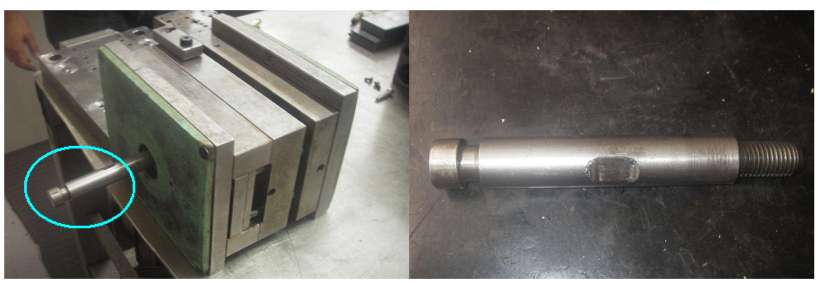
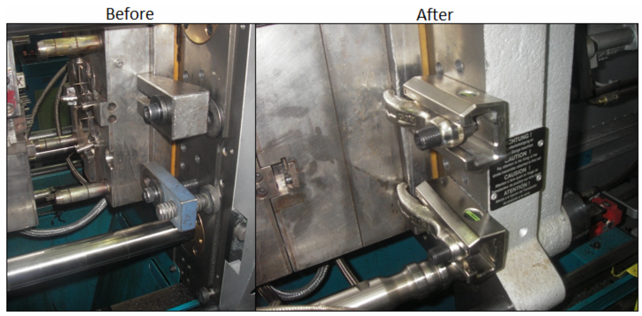


Figure 7:Connector between clamping cylinder and die

Concerning the streamline of changeover operations, clamping systems were improved, Figures 8(a) and 8(b), tools shadow boards were applied and a set of pre-established values was defined for the parameters in the machine's control panel. These parameters included temperature, amount of material injected, time of opening and closing the die, pressure and others.

(a)



(b)

Figure 8:(a) Security clamping system for transport, (b) die clamping system

In general terms, checklists and changeover instructions were created for all the machines, and techniques like 5S [26] were applied in order to improve workstations' organization.

Results and discussion

After SMED improvement proposals were implemented, their impact on performance was evaluated having into consideration the initial values of the performance measures selected and above referred. The necessary data was gathered before, as above referred, and after the SMED improvement proposals were implemented. As previously referred, in addition to changeover times, other three quantitative performance indicators were considered, namely WIP, annual changeover costs and distance travelled by the operators during a changeover. Table 1 shows the attained improvements on the changeover time, for each machine, for each of three stages of evolution of the SMED study. The improvements results are, in general, impressive, i.e., 58,7, 89,7 and 83,7 % improvement respectively for the Punch-Bending, Punch Press and Injection, moulding machines. Nevertheless, in the case of punch-bending machine the solutions adopted didn't achieve the single digit value for changeovers as aimed at by SMED. This simply means that there is still scope for improvement. In the other two machines the objective was accomplished.

Table 1. Improvements on changeover time for the three improvement stages.

Machines	**Changeover time (min)**				**Overall Changeover time improvement (%)**
	Initial	**1st stage**	**2nd stage**	**3rd stage**	
Punch-Bending Machine	188,15	146,02	108,00	77,80	58,7
Punch Press	61,80	54,00	52,33	6,35	89,7
Injection Moulding Machine	58,14	54,48	17,72	9,80	83,1

In addition to the improvements of changeover times, productivity, workstations ergonomic conditions and work organization were considerably improved too. In particular a clear and systematic procedure was established for each changeover in each machine, supported by checklists strictly followed by operators.

As expected, the reduction of batch sizes allowed by the decrease of changeover times has led to a reduction of WIP. Table 2 compares WIP values for metallic and plastic parts, before and after SMED study and implementation. The comparison reveals very significant WIP reductions, i.e., approximately 55 and 80% for both time and money, in the areas of metal and plastic components, respectively.

Table 2. Impact of the SMED solutions on WIP: Comparing before with after performance

Production area	**Average WIP (days)**			**Average WIP (€)**		
	Before	**After**	**Improve-ment (%)**	**Before**	**After**	**Improve-ment (%)**
Metal parts	17,05	7,74	54,6	318,75	144,38	54,7
Plastic parts	5,00	1,09	78,2	439,00	87,80	80,0

Changeover costs were also evaluated. Calculations were based on Equation (1). Results are shown in Table 3.

Table 3. Measuring costs and savings from SMED implementation

Machines	**Average annual changeover cost (€)**			
	Before	**After**	**Improve-ment (%)**	**Savings (€)**
Punch-Bending Machine	19.370,9	8.009,9	58,7	11.361,1
Punch Press	5.076,4	521,6	89,7	4.554,8
Injection Moulding Machine	4.840,0	815,8	83,1	4.024,2
			Total	19.940,1

The reduction of operators' movements was one of the important aspects contributing to the changeovers improvement. This was achieved by external operations concerned with placing near the machines all the necessary tools, devices, materials, documents and instructions. Table 4 shows the new values for the operators' travelled distance during a changeover occurrence.

Table 4. Comparing operators' movements before and after SMED implementation

Machines	**Travelled distance (m)**		**Savings (%)**
	Before	**After**	
Punch-Bending Machine	370	10	97,3
Punch Press	260	2	99,2
Injection Moulding Machine	300	10	96,7

When compared with the initial distance travelled values these results from the SMED study show dramatic savings, i.e., 97,3, 99,2 and 96,7%, respectively for the punch-bending machine, punch press and injection moulding machine.

Conclusions

Keeping up with competition in the economic global market of today, characterized by increasing product customization, requires efficient use of resources and customer service effectiveness. In manufacturing this is highly dependent on product flexibility. This means the ability to change production from one product to another without relevant additional costs. This contributes to both, customer service effectiveness, by providing quick response to demand, and to production efficiency, at several dimensions. However product flexibility should not be a burden on production capacity. To manage this SMED technology can give a fundamental contribution. This involves a methodology and a number of techniques and changeover strategies and solutions for quick product changeover.

This paper describes the application of SMED technology in a power controls industrial company of the north of Portugal in the production areas of metal and plastic components. After a brief literature review, the paper puts forward important strategies and techniques of SMED, emphasizing the importance of converting internal into external operations. Additionally two important strategies of high impact on reducing changeover times, namely quick centring and adjustment of dies at machines, for fast changeovers, and the use of parallel changeover operations, are briefly described.

The industrial case studied is described in line with most important SMED strategies and novel solutions. Many proposals were made with visible and impressive impact on changeover processes, in terms of time and cost savings, reduction of work-in-process levels and distance travelled by operators during the changeover process. Most of the proposals were implemented and the real impact of solutions assessed and reported. Quick changeovers allowed reducing batch sizes and increasing product flexibility, due to the increased number of product changeovers without burdening production capacity. A much smoothed production flow and smaller lead times were obtained.

In terms of changeover time, reductions ranging from 58 to almost 90%were achieved. The WIP of metal components was reduced from 17.05 to 7.74 days and from 5 to 1.09 days in the case of plastic components. The distance travelled by operators during changeover processes was dramatically reduced from 370 to 10 m (punch bending machine), 260 to 2m (punch press) and 300 to 10m (injection moulding machine).

The involvement of operators, as advocated by SMED, proved to be critical in the success of the study and its implementation. In addition to operators' participation in the implementation of solutions their contribution was also important for generating ideas for good solutions.

Although large benefits were obtained from this project, scope for further improvement still exists. In fact the objective of changeover times below 10 minutes aimed by SMED was not achieved for the punch-bending machine.

This project has clearly shown the potential of SMED to improve manufacturing efficiency and effectiveness of industrial companies.

Acknowledgments

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