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Single Minute Exchange of Die. A Case Study Implementation

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Abstract

The Single Minute Exchange of Die (SMED), a process-based innovation originally published in the mid 1980s, involves the separation and conversion of internal setup operations into external ones. Although very important in increasing productivity SMED experiences are not very widespread in Ibero-America. Accordingly, this article has as its main objective to contribute to the literature addressing this less studied topic: SMED. A case study was put forward emphasizing a process-based view. The main finding is that by implementing SMED techniques the firm managed to eliminate wastefulness and non-added value activities worth around 360 000€, which is about 2% of the firm's sales volume.

Keywords: SMED methodology; changeover; setup; process innovation.

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Introduction

The last two decades have been witnessing great changes in the management and organization of the production systems in industrial firms all around the world. Two important innovations underpinned these changes: the technological revolution and the proposition of new managerial philosophies. The former is felt throughout the world due to new information systems, machinery, telecommunications, pervasive automation and robotics, that underpinned unprecedented productivity gains and better operations planning and control. The latter allowed a larger focus on internal resources as most of the firms realized that the qualification of their human resources constitute a strong differentiating element in making the firms faster and more flexible in the business world (Womack et al,. 1990).

Innovation is now recognized as one of the key success factors for the improvement of productivity (Freeman and Soete, 1997; ODCE, 1997; Utterback, 1971). Although newness, creativity and invention are behind the concept of innovation, this is structured around three main blocks: products, processes and organizations (European Commission, 1995).

While product innovation is intimately related to the development of new technologies and to new products to satisfy market needs, process innovation is related to new elements, equipment or manufacturing methods to improve the production of a product or to provide a better service (Utterback and Abernathy, 1975; Damanpour, 1991; Damanpour and Gopalakrishnan, 2001).
Ettlie and Reza (1992) and Frost and Egri (1991) defend that process innovations are less tangible and more difficult to implement than product innovations. Daft (1992) defends that product innovations are easier to imitate and that process innovations are more organization specific, given that they cannot be copied without implementing changes in the organizational structure or in the management system (Ettlie and Reza, 1992; Damanpour, 1996).
Following an organizational perspective of innovation, it is possible to distinguish two types of innovation processes: the company as provider or user of innovation. As provider of innovation it faces problems and makes decisions that imply the development of new products and processes (Utterback, 1971; Pinchot, 1985). The company's success as an innovation provider stems from its exploration capacity and the possibility to profit from this innovation (Gopalakrishnan and Damanpour, 1997). With this behavior the firm follows an outward innovation process.

As a user of innovation, the firm tries to incorporate newness developed outside the firm. Zaltman, Duncan and Holbek (1973) differentiated between two stages in this innovation process: initiation and implementation. The former includes activities that deal with the perception of the problem, the gathering of information and the development of an attitude that promotes and assesses innovation. The implementation stage is related to the decision making regarding the adoption of innovation. Although in the initiation stage competences possessed by individuals are important, group competences are essential in the implementation stage, since it is more systemic and involves the organization of the internalization of the innovation (Damanpour, 1992). As a user of innovation the firm follows an inward innovation process.

The Toyota Production System (TPS) is clearly one of the vivid examples of process innovation. The main objective of the TPS was to increase manufacturing productivity using techniques such as small-sized production lots, non-stock production, with strong focus on product and process quality and preventive maintenance (Pisano and Hayes, 1995; Godinho Filho and Fernandes, 2004).

The gains obtained with these process innovation techniques have been remarkable (Hall, 1983; Plossl, 1985; Womack et al, 1990; Hay, 1992). Nevertheless, the implementation of the Japanese process innovation-based techniques have had limited impact in the West (Lamming, 1993; Nishiguchi, 1994; Freire, 1995; Dyer, 1996).

The development of new management techniques, taking into account limited production resources, is on high demand as product demand is shrinking and the competition is ever stiffer. Accordingly, the better the efficiency of the firm in managing its production resources the better the firm is to respond to the competitive challenges through improved operational performance (Blau, 1994).

The SMED (Single Minute Exchange of Die) methodology, developed by Shingo (1985), was developed in order to reduce and simplify the setup time during change-over. SMED, which is also a Japanese process-based innovation, makes it possible to respond to fluctuations in demand

and results in lead time reductions, while also eliminating wastefulness during change-over and diminishing lot sizes (Shingo, 1985; Womack and Jones, 1998).

Traditionally firms regarded setup times as one of the most expensive costs they had to face and opted for both the minimization of the number setups implemented and for very large production lots (Holweg, 2006). This method contributed to an excessive inventory because they produced more than they needed to satisfy customers needs (Likert, 2004). Nowadays the general understanding is that mass production has become obsolete as production costs have increased and efficiency has decreased steadily (McIntosh et al., 2000; Holweg, 2006). Today firms are forced to compete, simultaneously, in terms of price, product quality, product differentiation and delivery time. To improve production processes it is necessary to analyze the value added by each activity and eliminate all those that do not add value to the product (Levinson, 2002), which makes the SMED methodology extraordinarily important.

Firms that produce a large diversity of products have to implement production processes that are capable of satisfying all of the customers' needs. Frequently, the time necessary for the company to implement its setup operations limits the firm's capacity to satisfy its customers' needs. Nowadays, with the large diversity of products necessary for the same demand, firms are forced to produce smaller lots without harming their global productivity (Blau, 1994). Thus, firms must be capable of producing a large diversity of products in small quantities and, consequently, must provide for much more frequent tool changes. In order to compete, firms have to find ways to reduce setup times, eliminate wastefulness and non-added value activities and convert idle setup time into regular production time, which means that a strong focus on process innovation is needed.

Having identified the main problem, the firm's challenge is to minimize the setup times, which can be accomplished following the SMED methodology. In order to implement this process-based innovation, setup operations have to be standardized and properly documented in order to ensure that production workers follow all of the parameters of that process (Nicholas, 1998).

Although some SMED results have been described and presented widely (Monden, 1984; Johansen and McGuire, 1986; Sepheri, 1987; Quinlan, 1987; Noaker, 1991; Gilmore and Smith, 1996; McIntosh et al, 2000), studies about SMED implementation are in short supply in Ibero-America (Silva and Duran, 1998; Fogliatto and Fagundes, 2003; Satolo and Calarge, 2008; Sugai, McIntosh and Novaski, 2007). As a consequence, and taking into account a SMED pilot project implemented in a manufacturing firm in the North of Portugal during 2008, the major endeavor of this paper is to present a case study about the implementation of the SMED methodology and report the insights gained.

The article is divided into five sections. The introduction of the article is to be found in this first section. The second section addresses the literature review. The third section deals with the methodology used. The fourth section addresses the field work. Finally, in the fifth section the conclusions are drawn.

Literature Review

Single-Minute Exchange of Die (SMED) refers to the theory and techniques used for the reduction of equipment setup times. SMED has as its objective to accomplish setup times in less than ten minutes, i.e. a number of minutes expressed by a single digit. Although not all setups can be literally reduced to this time, between one and nine minutes, this is the goal of the SMED methodology (Shingo, 1985).

SMED, also known as Quick Change Over of Tools, was developed by Shingo (1985), who characterized it as a scientific approach for the reduction of setup times, and which can be applied in any industrial unit and for any machine. SMED is defined as the minimum amount of time necessary to change the type of production activity taking into consideration the moment in which the last piece of a previous lot was produced vis-à-vis the first piece produced by the subsequent lot (Shingo, 1985).

Before the development of the SMED methodology, the best way to minimize the cost of idle machines during setup operations was to produce large lots, in order to obtain the lowest possible percentage of idle time per unit produced. According to Min and Pheng (2007), the ideal amount of each production lot was obtained when the inventory costs equaled the costs of idle equipment during the change over of tools.

Toyota came across this problem because inventory costs for their vehicles were extremely high. Before this problem, the best way to reduce the amount of production loss was to reduce setup times (Shingo, 1985). Thus, if production changes could be done in less time, the ideal amount of production could be smaller, which, consequently, would decrease the costs involved. The question around the optimum amount of the production lot remains as it is necessary to calculate the minimum amount for each production lot. The production of large lots also has inherent capital costs with the amount invested in inventory. If we add to this inventory cost the capital opportunity cost, it is no longer profitable to produce large lots.

The computation of the Economic Order Quantity (EOQ) includes the time of production of each lot and the line setup time (Min and Pheng, 2007). If the setup time increases, then the production lots must also increase, in order for each unit to be produced in the smallest possible time. Besides this point, Abdullah (2007) refers that the EOQ is very difficult to apply because it is very complicated to accurately calculate the number of defective pieces in each lot produced. In any event, this concept is intimately linked to SMED, since the setup time is of vital importance for the production time of each lot.
In table 1 the relationship between lot size and production time per unit is exhibited. It is possible to conclude that the larger the lot size the lower the production time per unit, due to the breakup of the setup time into a larger number of units. Table 1 also exhibits the relationship between the equipment operation time and the idle time during tool change.

Setup Time	Lot Size	Production time per unit	Operation time per unit	Ratio
8 Hrs	100	5.8 min	1 min	580%
8 Hrs	1 000	1.48 min	1 min	48%
8 Hrs	10 000	1.048 min	1 min	5%

Table 1. An Example of the Calculation of Unit Production Times as well as of the Relationship Between Tool Change and Production Time. Data based on Shingo (1985).

With some simple calculations it is possible to demonstrate the productivity yield as a consequence of the SMED methodology.
Let us suppose that the setup time of a certain machine takes three hours, its cycle time lasts one minute, the lot size is of 100 units and the cost of the machine 48€/h. The production cost per unit is:

$$Unit\_Cost = \frac{Setup\_Time + Production\_Time}{Lot\_Size} x \frac{48}{60} = 2.24€/unit$$

If the setup time were reduced to 9 minutes it would be possible to obtain a cost of 0.87€ per unit. On the other hand, if we maintained the same setup time and we wanted to obtain the same cost per unit, we would have to produce not 100 pieces, but lots of 1997 pieces. As a consequence, the following disadvantages would be made apparent:

• The need for larger client orders;
• Longer lead times;
• Larger costs with inventory, pallets, forklifts, labor, among other things;
• Larger quality problems (probable);
• Loss of money with inventory amortization;
• More labor linked to transport and inventory;
• More frequent refunds due to larger amounts of defects (probable).

According to Shingo (1985), the main benefits of the SMED application are presented in table 2.

Direct
- Setup time reduction - Reduction of time spent with fine tuning - Fewer errors during change-overs - Product quality improvement - Increased safety
Indirect
- Inventory reduction - Increase of production flexibility - Rationalization of tools

Table 2. Expected results using the SMED application. Data based on Shingo (1985).

One of the most important objectives of SMED is the reduction of setup times, through the elimination of the wastefulness related to the change of tools. Thus, what is intended with SMED is to try to separate internal operations – namely the Die exchange or the fitting of the equipment, which have to be performed with the machine in switched off mode – from external operations – namely those performed with the machine in normal operation mode, as is the case of the preparation of tools.
According to Shingo (1985), SMED should be implemented in four different phases:

• Phase A, in which the firm makes no distinction between internal and external setup operations and consequently machines remain idle for very long periods of time. The main objective in implementing the SMED methodology is to study the shop floor conditions in great detail through a production analysis, interviews with workers and video-taping of the setup operations.
• Phase B, in which the firm separates internal from external setup operations. Usually, this action saves 30% to 50% of the time for the setup operation. Mastering this distinction is a key issue to achieving success in implementing SMED.

• Phase C, in which the firm converts the maximum internal setup operations to external ones. In this phase it is important to re-examine all operations in order to assess if they were wrongly assumed as internal ones and convert them to external ones.
• Phase D: Streamlining all aspects of the setup operation. This phase seeks the systematic improvement of each basic operation of the internal and external setup, developing solutions to accomplish the different tasks in an easier, faster and safer way.

Figure 1 exhibits the different phases of the whole process. Clearly, the idle production time diminishes as the process moves forward.

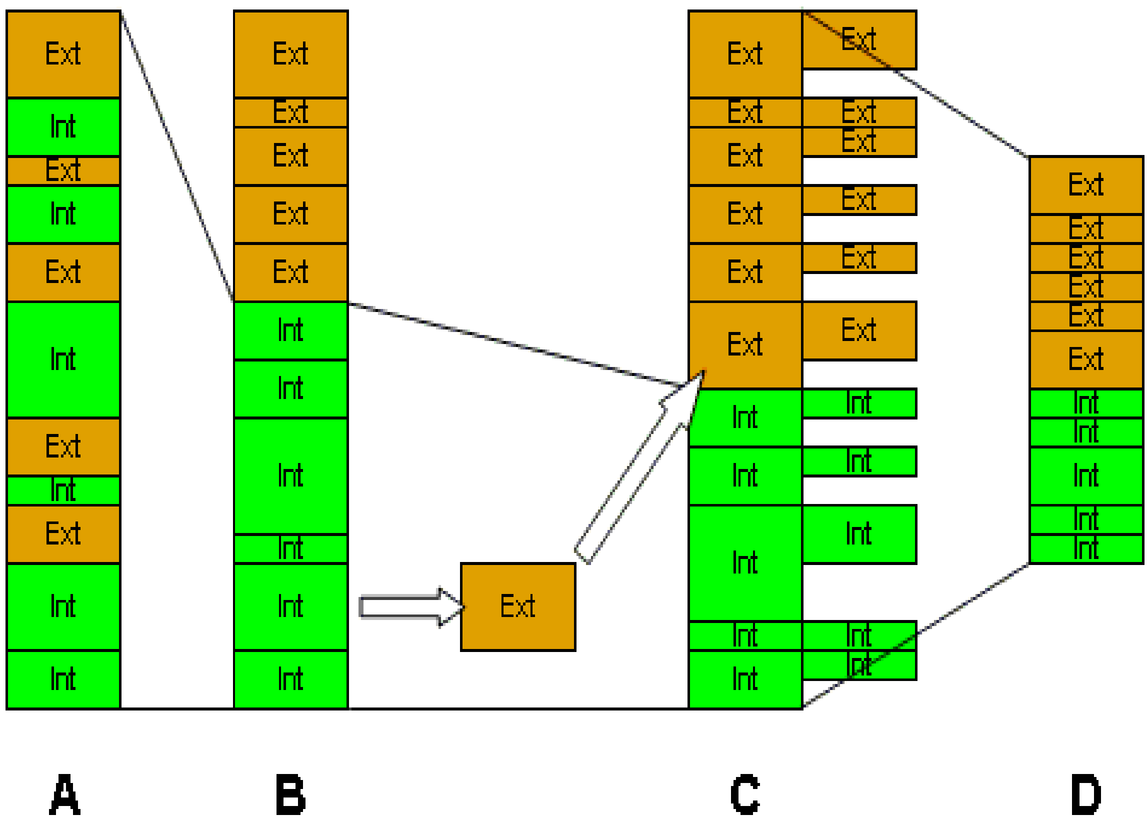

Figure 1. The phases of the SMED methodology. Data based on Shingo (1985).

One of the main difficulties in the application of this methodology is in the identification and classification of the operations. Shingo (1985) defines as external setup operations all those that can be performed while the machine is in operation. In opposition, internal setup operations are all those operations that can be performed only when the machine is stopped.

Shingo (1985) describes, quite exhaustively, a set of procedures that must be followed to reach global success during the SMED implementation:

- To analyze the actual procedure;
- To classify the several operations performed as internal or external ones;
- To convert the internal operations into external ones;
- To develop solutions that allow to reduce the time of the internal operations;
- To develop solutions that allow to decrease the time delays in the external operations;
- To create rigorous procedures in order to reduce flaws during the setup;
- To return to the beginning of the process and to repeat the whole procedure to reduce the setup time, continuously.

This set of procedures requires a continuous analysis of the process in order to obtain good results. Whenever the method is applied new improved solutions must be obtained.

There are some adaptations to Shingo's (1985) methodology. For example, Monden (1984) defends the conjoint analysis of all internal and external operations and the standardization of all functions. On the other hand, Gilmore and Smith (1996) defend that Shingo's (1985) procedures can be applied even when not following his logical sequence. Moxan and Greatbanks (2001) defend the use of a preparatory/learning phase in order to reach a better implementation of SMED and Fogliatto and Fagundes (2003) identify four types of activities when implementing SMED: strategic, preparatory, operational and confirmatory activities.
Due to the objective originally set out by this research, Shingo's (1985) methodology was used initially and, in the diffusion process, Fogliatto and Fagundes' (2003) proposals were introduced.

To make the SMED implementation smoother a group of leveraging tools (McIntosh et al., 2007), was also used. They are mentioned in table 3.

Phases of the SMED concept	Leveraging tools
Phase A: SMED project kick off	(1) Analyze the Shop Floor activities in order to differentiate internal from external operations
Phase B: Separate internal from external operations	(2) The use of *checklists* (3) The definition of functions for each worker (4) The improvement of tool transportation
Phase C: Convert internal to external operations	(5) The previous preparation of setup operations (6) The automation of operations (7) The utilization of different tools
Phase D: Improve all aspects of the setup operation	(8) The improvement of tool transportation and warehousing (9) Elimination of settings, calibrations and adjustments (10) The automation of operations

Table 3. List of tools used in the implementation of the SMED methodology.

Research Methodology

In order to achieve the original goal proposed in the first section, and taking into account the main objective of the firm, it was decided that we would follow a qualitative approach and thus prepare a case study (Yin, 1989).
The case study reported herein took place during 2008 in a mold making firm, which will be named ALFA due to confidentiality reasons, located in the North of Portugal. It was set up in 1995 and is part of one of the leading Groups of the main mold making industry in Portugal. In 2008 ALFA had a sales volume close to 18 million Euros and around 420 employees. While table 4 exhibits some of ALFA's characteristics, table 5 presents some of ALFA's machinery. Although ALFA has a diversified group of clients, their main clients belong to the European automotive industry.

Nº employees	Nº Setups Per day	Sales Volume	Operational EBIT	EBIT p/capita
420	24	17 620 000€	1 720 000€	4 659€

Table 4. ALFA's main data.

Product Diversity		
Final references per month	1 052	
Pieces sold per month	2 432 185	
Types of Machines and Molds	**Qt. machines**	**Molds**
<299 Tons	20	134
300< <999 Tons	24	115
> 1000 Tons	2	4

Table 5. ALFA's machinery data.

The headquarters of the GROUP is in the North of Portugal. The GROUP has more than 20 "independent" firms and business units in more than 10 countries. Its sales volume, in 2008, was around 350 million Euros.

In order to implement the case study it was decided to follow the steps shown in figure 2. The first step involved a review of the literature and the selection of ALFA as the target firm in which to implement the SMED project. The second step involved the definition of the goals to be achieved at ALFA with the SEMD project. Finally, the third step involved the development of a procedure to implement the SMED methodology.

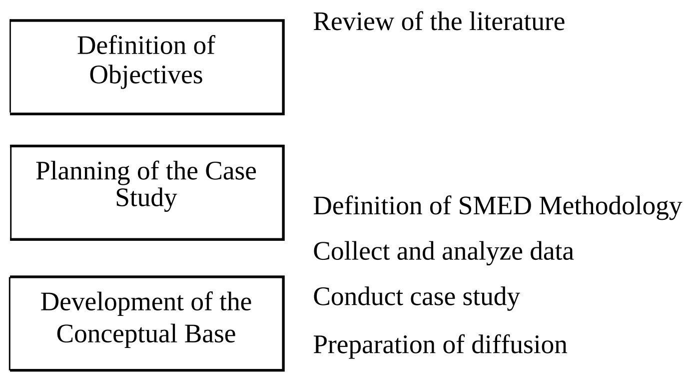

Figure 2. Steps followed during the case study.

The review of the literature was implemented before the formal beginning of the project as was presented in section two. The selection of ALFA was easily achieved as there were some contacts between ALFA and the University of Aveiro in which both institutions signed a protocol to deploy the SMED project.
The second step was defined taking into account ALFA's wishes of firstly to deploy the SMED project following a learning-based approach and then to diffuse the SMED methodology implemented in ALFA to the other firms of the GROUP. As part of this learning-based approach ALFA decided that the SMED project would be implemented first without any product-based innovation or any investment in new technology in order that the different SMED teams within ALFA could internalize the SMED insights as much as possible.

Finally, the third step, which is the core of the project, is going to be presented in section 4.

Case study field work: SMED Implementation at ALFA

The work performed at ALFA had as its natural objective the improvement of the production system, and was divided in the following phases:
1. Analyzing the setup operations on the shop floor, recording the whole setup process and describing the setup operations, tracking setup times and measuring die casts movements;

2. Separating internal from external operations;
3. Converting internal to external operations;
4. Streamlining all aspects of the setup operation in order to accomplish the different tasks in an easier, faster and safer way;
5. Assessing the impact of the methodology implemented;
6. Preparing the diffusion of the new SMED methodology to the other firms of the economic group.

Analysis of the Setup Operation on the Shop Floor

The initial analysis was very important for obtaining a correct diagnosis to underpin the improvement of the negative aspects of the production system. The results obtained in this phase are also important for a subsequent assessment of the impact of the adopted solutions. Thus, the purpose of this analytic phase was to pick up all of the information possible regarding the setups, such as:

- The sequence of shop floor operations;
- The timings of the different tasks and operations;
- The organization of workers during the setup and the machine work rates;
- The identification of critical points that reduce the effectiveness of the production system, as well as its causes.

In the initial stage of the analysis, the strategy implemented was based on (a) the observation and assessment of both the production system and the setup operations, and (b) in individually interviewing the team of workers that carried out the setup operations. The second stage involved gathering documentation on the several observed setups. For that purpose data from ALFA's information system were compared with data picked up through the observation of the production process.
The analysis of the production system took place during the setups and the following aspects were analyzed:

- The standard procedures;
- The communication among workers;
- The performance of each worker in accomplishing his or her function;
- The capability and motivation of each worker in the performing of their respective tasks;
- The difficulties felt by workers during setup operations;
- Settings, calibrations and adjustments during the setup;
- The coordination among the production, quality and logistics departments.

Part of the analysis included interviews with personnel involved in the SMED operations. After interviewing the workers involved in the setup operations it was decided to carry out interviews at several hierarchical levels.

The interview with the head of the process department had as its main purpose the acknowledgement of the organic function of the department and to get acquainted with the worker's functions in the production system.

The interviews also involved the three ALFA production sections heads, the maintenance department head and the SMED teams head. The main objective of these interviews was to acquire knowledge regarding the procedures used by the different heads during the setup operations.

Finally, several interviews took place with the workers involved in setup operations. These interviews targeted the knowledge of the whole setup process, namely the sequence of the operations, the major difficulties faced, the type of training, the development of skills, the quality assessment, etc.

After the interviews it was decided to gather and analyze data of the setup operations. ALFA possessed some data in its information system regarding production and setup times that were helpful during the analysis. These data constituted an initial work base, because it was possible to obtain production times, setup times and detailed times of setup operations. However, some data did not match with reality due to mistakes in the recording process of the setup activities.

In order to overcome this problem an analysis of the organizational procedure of the setups was performed involving the logistics department, the production department, the heads of the production sections, the production line supervisors and the SMED teams. The procedure was approved by the production manager. Thus, it was possible to characterize the setups and to detail all the procedures in order to facilitate a more realistic analysis, which involved the identification of all operations and its evaluation using some videotaping and stopwatches.

The readiness and the cooperation of the SMED team helped us to notice how the whole setup process worked in full detail.

The new data generated were compared with those recorded in the information system. When differences were found the correct data were introduced in the data base. With the implementation of the procedure and the gathering of data of setup operations it was possible to conclude that the setup process involves a large number of people and departments. Accordingly, if the interaction among them is not adequate, the inefficiency may endure. Throughout the study it was possible to conclude that this interaction was one of the greatest problems in the setups and it originated a lot of inefficiency in the whole production process.

After the setups observation and assessment it was possible to classify the procedure in four phases:

• Take out old Die;
• Insert new Die;
• Prepare new Die for injection;
• Set, calibrate and adjust new parameters.

Table 6 shows the percentage of the time spent in each of the setup phases at ALFA. Clearly, the three most important ones, which involve more than 90% of the time, are the following: take out old Die; insert new Die; and setting, calibrating and adjusting new parameters.

Phases of the SMED	Percentage of time
Take out old Die	25 %
Insert new Die	32 %
Prepare new Die for injection	8 %
Tuning new parameters	35 %

Table 6. Percentage of time spent in the setup phases.

An assessment of the time spent in each of the setup phases made it possible to conclude that idle time was the result of the following situations:

• Lack of coordination among workers involved in the setup;
• Lack of fulfillment of the pre-established procedures for carrying out the setup;
• Lack of knowledge of the procedures for carrying out the setup;
• Water hoses, oil, electric material and Die tools in poor conditions;
• Too much time in the preparation of new Die due to raw material delay and stove cleaning;
• Delays due to shortage of material/tools near the equipment;
• Delays due to the absence of a SMED team member, who was assigned to other tasks;
• Lack of coordination of the various setups.

The following phase consisted in the assessing of all setup operations. In this phase several setups were observed and the timing of all operations recorded.

As mentioned before, ALFA utilizes a wide range of Dies, from 80 Tons to a maximum of 1100 Tons. The high-end Dies demand larger amounts of manual labor (and time) in the setup operation than do low-end Dies. Thus, the assessment of the different types of Dies was divided into the following three groups:

• Low-end: Dies with tonnage lower than 299 T.
• Medium-end: Dies with tonnage between 300 and 999 T.
• High-end: Dies with tonnage larger than 1000 T.

Table 7 exhibits the setup time of a sample of six machines for each group. Clearly, there is a wide range of variation for the setup time, 72 minutes being the average of the low-end sample, 89 minutes the average of the Medium-end sample and 125 minutes the average of the high-end sample. As a consequence, it can be concluded that the setup process is unstable and out of control.

	Low-end	Medium-end	High-end
Sample 1	53	65	97
Sample 2	62	80	98
Sample 3	64	84	102
Sample 4	67	89	117
Sample 5	78	106	158
Sample 6	88	113	180
Average	**72**	**89**	**125**

Table 7. Setup times of groups of Dies.

Table 8 exhibits setups times – minimum and average, in minutes – accomplished by internal operations for the three different ranges of Dies.

Tasks	Low-end		Medium-end		High-end	
	Minimum	Average	Minimum	Average	Minimum	Average
Stop machine and open Die	00:01:02	00:03:56	00:04:47	00:06:56	00:07:50	00:08:49
Oil the guide and introduce release agent or protective template	00:02:03	00:01:34	00:02:43	00:03:34	00:04:33	00:06:31
Remove water and oil hoses	00:04:10	00:04:12	00:04:21	00:06:12	00:07:22	00:09:23
Introduce rings and oil the hoses	00:01:30	00:01:14	00:01:02	00:02:14	00:03:17	00:04:24
Remove the mold clamping bars	00:02:09	00:01:59	00:01:58	00:02:59	00:03:58	00:04:45
Remove the stem extraction	00:02:03	00:02:04	00:02:11	00:03:04	00:04:10	00:04:35
Remove the mold from the machine	00:02:08	00:08:08	00:04:17	00:09:08	00:06:11	00:10:46
Read the injection program/robot	00:01:08	00:02:28	00:02:33	00:01:28	00:02:11	00:02:34
Place new mold in the machine	00:03:09	00:03:07	00:03:12	00:04:07	00:05:12	00:06:42
Introduce the stem extraction	00:02:03	00:03:45	00:03:46	00:04:45	00:05:53	00:06:51
Turn on mold heater	00:00:45	00:00:59	00:01:03	00:00:59	00:02:59	00:04:39
Put the grip bars	00:04:23	00:05:16	00:05:27	00:06:16	00:07:24	00:07:19
Remove safety bars	00:00:53	00:01:12	00:01:14	00:01:12	00:03:02	00:04:18
Open the mold and tight the stem extraction	00:07:23	00:07:12	00:07:15	00:09:12	00:08:05	00:09:01
Reset and open the machine	00:01:10	00:01:45	00:01:46	00:01:45	00:02:57	00:03:53
Put on water and oil hoses	00:04:12	00:05:29	00:05:27	00:05:29	00:06:21	00:07:21
Clean the mold and the line joins	00:01:02	00:01:35	00:01:38	00:01:35	00:03:31	00:04:19
Purge spindle	00:05:14	00:05:23	00:05:21	00:07:23	00:07:21	00:04:19
Tune the machine	00:03:02	00:06:15	00:04:12	00:07:15	00:06:28	00:08:28
Inject a good part	00:03:34	00:02:59	00:02:57	00:03:59	00:04:51	00:05:49
TOTAL TIME	0:53:03	**1:12:32**	1:07:10	**1:29:32**	1:43:36	**2:04:46**

Table 8. Minimum and average setup times of the three groups of Dies.

As can be observed in table 8, the setup times of the different activities for the three groups of Dies vary widely, within and between groups. During the visualization of the several setups it was possible to identify many of the causes for these variations in time. The following are among the most important ones:

• Poor organization, since the several setup operations on the shop floor and the people involved in the setups were not synchronized;
• Inadequate or absence of setup preparation;
• Lack of knowledge of the procedures for carrying out the complete setup in time;
• Lack of fulfillment of the established check-list of activities for carrying out the setup;
• The carrying out of external operations as if they were internal ones;
• Lack of a planned procedure deploying operators to setup operations, which creates some idle time in carrying out the setups.
• Poor conditions of maintenance tools and Die tools.
• Lack of contiguous space for relocating old/new Dies.

Separating Internal from External Operations.

In this phase the setup operations were analyzed in order not only to separate internal from external operations, but also to identify external operations that were taking place together with internal operations.

Separating internal from external setup operations involves distinguishing all the activities of the setup operation and to divide the setup in stages. Thus, the setup was

divided into the following four stages:
1. operations to be accomplished one hour before the machine stops;
2. operations to be carried out immediately before the machine stops;
3. operations to be carried out during the setup operation;
4. operations to be accomplished after the machine is back to normal production.

Table 9 exhibits all activities that are proposed to be accomplished in the proposed first stage, which are external operations and related to the setup preparation. Table 10 lists the (external) operations to be carried out immediately before the machine stops. They can be easily carried out in a very short time. Table 11 mentions all the activities to be carried out during the internal setup operation. Finally, table 12 exhibits the tasks to be accomplished right after the machine is back to work.

External setup operations	Time
Place the mold near the machine	00:03:00
Preheat the mold	00:01:00
Prepare the eyes for the incoming mold and outgoing mold	00:01:00
Prepare the mix-injector jet and the rings in the tools car	00:00:40
Check up the file tuning	00:01:00
Prepare hoses	00:02:00
Forecasted time withdrawn from internal setup	**00:08:40**

Table 9. List of operations to take place long before the equipment stops.

External setup operations	Tempo
Place bridge on the machine	00:00:45
Place the tools car near by the machine	00:00:35
Turn off the heating box of outgoing mold	00:00:10
Place the washers in the incoming mold	00:00:45
Forecasted time withdrawn from internal setup	**00:02:00**

Table 10. List of activities to be carried out right before the equipment stops.

1 – Stop machine and open Die
2 – Oil the guides and put release agent or protective template
3 – Remove water and oil hoses
4 – Put rings and turn off de heating
5 – Remove the template clamping bars
6 – Remove the stem extraction
7 – Remove the mold from the machine
8 – Read the injection program / robot
9 – Put new mold on the machine
10 – Introduce the stem extraction
11 – Turn on the mold heater
12 – Put the squeeze bars
13 – Remove the safety bar
14 – Open the mold and tight the stem extraction
15 – Reset and open the machine
16 – Put on the water and oil hoses
17 – Clean up the mold and the line joins.
18 – Purge the spindle
19 – Tune the machine

Table 11. Operations to be carried out during the setup operation.

Fix the tool on the car
Put in the appropriate place the various tools
Clean and tide up the place of change
Arrange the documentation of the previous template

Table 12. Activities to be accomplished right after the machine is back to work.

Among the set of operations to take out the old Die and to insert the new Die, the SMED team was performing an external operation as an internal one: one member of the SMED team was taking out the old Die and transporting it to the Dies warehouse to, finally, transport the new Die to the machine. Figure 3 shows this operation.

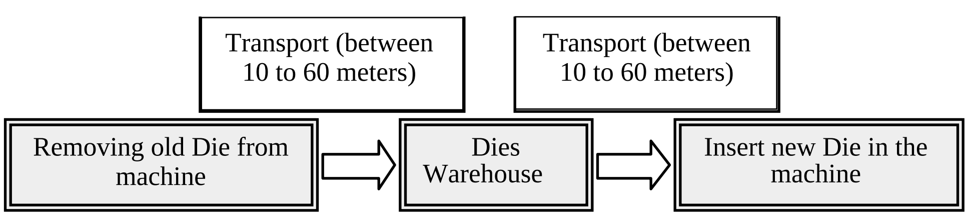

Figure 3. Movement of the mold during the setup.

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This transport operation is clearly an external operation, since it can be accomplished right before and after the beginning of the following production run. So, the new proposal for changing this situation is the following: previous to the setup preparation, the new Die is placed next to the machine in which it will be inserted; then, during the setup, the old Die is removed, shifted sideways and placed next to the new Die; then, the new Die is introduced in the machine. Figure 4 shows this new operation.

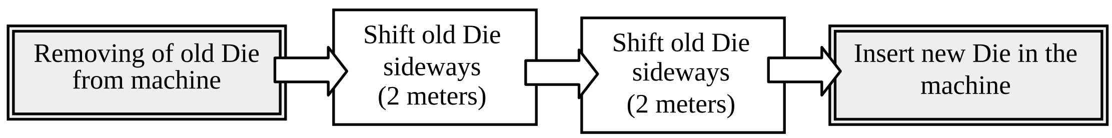

Figure 4. Movement of the mold with the setup change.

With this change it is possible to decrease the setup time by seven to ten minutes, depending on the distance of the machine to the Dies warehouse, which is possible by transporting the Die to its storage as an external operation.

While preparing the setup it was realized that preparing the hoses for the new mold, while placing water hoses and oil next to the machines, could be an external operation as it could be accomplished before the setup. As a consequence, the SMED team must analyze the checkup procedure and prepare the water hoses and oil before the setup. With this small change it is possible to decrease the setup time by about two minutes in average.

Converting internal to external Operations

Another important observed aspect was the total lack of previous preparation of the Die. Actually, the Die is placed and inserted in the machine just as it was stored. A possible solution for converting an internal operation to an external one is to turn on the heating resistance of the Die fifteen minutes before the setup is planned to begin, in order for the Die to be at a working temperature when placed in the machine

With the implementation of this measure this operation takes place as an external one and not during the setup. Moreover, it is estimated that the heating of the Die before the setup operation has another important advantage: it saves between five to seven minutes of the operation of calibrating and adjusting of the machine. Another important problem faced was the stabilization of the operating temperatures of the Die, which takes between five to fifteen minutes. If the company used an internal heating control device, extra time could be saved during the setup.

Streamlining all aspects of the setup operation.

In this phase the objective is to accomplish the different setup operations in an easier, faster and safer way. In order to obtain positive pervasive effects of the application of the SMED methodology it was decided that firstly it would be mandatory to generate an internal knowledge perspective so that the improvements be deployed throughout the organization and secondly, after the firm has internalized this new knowledge, to deploy the SMED methodology for the rest of the firms in the GROUP.
As mentioned before, during the diagnosis (see section 3.1?) it was possible to witness a lack of coordination of the various setups, due to poor production planning as well as poor coordination of the workers involved in the setup. In order for the first step to be successful it was decided to focus on two different strands: at an operational level as well as at an organizational level.
At an organizational level it was decided to propose a SMED supervisor due to the lack of communication between the workers and the SMED teams. This SMED supervisor would be responsible for the training of the members of the SMED teams and for the programming

and control of all the setups on the shop floor. During the project, and in order to avoid any misunderstandings within ALFA's organization chart, this SMED supervisor would report to both the Production manager and to the logistics manager (in fact, this SMED supervisor was role playing a project coordinator role in a matrix organization).

With this SMED supervisor it was possible to achieve the following advantages:

• to facilitate the SMED procedures among all teams and team members;
• to plan all the setups with the logistics and production managers;
• to deploy the SMED procedures following a learning-based approach in which all the SMED team members can contribute to a better setup control;
• to prepare in advance all the setups reducing the time with external setup operations and minimizing the internal setup operations.

At an operational level it was possible to coordinate the various setups and to define new standards for all the setups. In the mean time both the logistics and the productions managers could internalize the intricacies of the SMED procedures and were better acquainted with the new improvements. With their involvement it was also possible to (a) improve the data base with the timing of the startup operations, and (b) to present the results to ALFA's board of Directors.

Economic Impact of the SMED Methodology

With the implementation of this SMED Project, and after converting internal to external operations it was decided to analyze the economic impact of the actions so far implemented. In table 15 it is possible to witness the time gained with the new SMED procedures for each group of machines. The base for comparing both results, the previous and the new procedure, was based on the average time involved in the setup times.

Operation	**Previous Procedure**			**New Procedure**		
Type of Machine	Low-end	Medium-end	High-end	Low-end	Medium-end	High-end
Remove old Die and insert new Die	00:08:08	00:09:08	00:10:46	00:01:08	00:01:08	00:00:46
Insert water and oil hoses	00:05:29	00:05:29	00:07:21	00:04:29	00:03:29	00:04:21
Calibration	00:06:15	00:07:15	00:08:28	00:01:15	00:01:15	00:01:28
Total	00:19:52	00:21:52	00:26:35	00:06:52	00:05:52	00:06:35
Time recovered				00:13:52	00:16:52	00:20:35

Table 15. Comparison of times involved in the SMED procedure.

The estimated impact for the total setup time after the application of the new procedures, for ALFA's different machines ranges, is presented in table 16. Clearly, the time recovered was equal to 46% in the low-end range, equal to 44% in the medium-end range and equal to 32% in the high-end range. With the reduction of the setup times, idle production will be drastically reduced as well. Table 17 presents the computation used to estimate the gains in setup time and, consequently, the increment of available time for production, based on 12 setups a day.

	Before	After	Yield
Low-end	01:12:32	00:39:11	00:33:20
Medium-end	01:29:32	00:50:18	00:39:14
High-end	02:04:46	01:23:01	00:41:45

Table 16. Estimated impact of total setup time. Table 16. Estimated impact of total setup time.

	Previous Situation			**Future Situation**		
Groups (T)	Low-end	Medium-end	High-end	Low-end	Medium-end	High-end
Nº Setups per day	5	6	1	5	6	1
Setup time per day	(5x72min) 360 min	(6 x 89min) 534 min	(1x125min) 125 min	(5x39min) 195 min	(6x50min) 350 min	(1x83min) 83 min
Total setup time	1019 minutes			628 Minutes		
Production time recovered *				165 minutes	183 minutes	42 minutes

Table 17. ALFA's setup times before and after the implementation of the SMED methodology.

In order to calculate the economic yield of the SMED procedure, we decided to ask ALFA's directors the average cost per hour for each group of machines. The values given by ALFA's board are presented in table 18.

Groups of Machines	*Cost*
Low-end	*60 €/h*
Medium-end	*200 €/h*
High-end	*400 €/h*

Table 18. Average cost for idle production by type of machine.

The annual estimated economic impact with the SMED implementation is presented in table 19: 362 960 €, which is around 2% of ALFA's sales volume for 2008.

Economic impact with the SMED implementation (344 days)			
	Low-end	**Medium-end**	**High-end**
Time gained	946 hours	1049 hours	241 hours
Value yielded	56 760 €	209 800 €	96 400 €
Total economic yield for one year			
362 960 €			

Table 19. Estimated economic yield with the SMED implementation.

Preparation of the Diffusion of the SMED Methodology

The first strategic step involved the deployment of the methodology implemented at ALFA to the other firms of the GROUP. This involved the training of the SMED team members as well as other production employees in order to spread out the results so far achieved within ALFA. This step was achieved in a short time frame (between 20 to 30 days).

At the operational level all shop floor operations involving set up activities must be analyzed systematically and for each one of them a checklist containing the description of the activities, the identification of internal and external operations, the average setup time and the operators with training to perform them must be developed. This checklist will allow the SMED coordinators to assess all setup activities.

Once a steady state of SMED operations has been reached at ALFA, the continuous quality improvement teams should include in their portfolio of activities the identification of internal and external setup operations for all operations, the conversion of internal setup operations to external ones, the reassessment of all conventional procedures in order to generate the improvement of the setup times and the deployment of brainstorming sessions to integrate aspects not yet included in the analysis of SMED activities such as plant layout, total quality management, total maintenance management and equipment design changes.

The actions of the continuous quality improvement teams should be moderated with the definition of new targets for the setup times of all SMED operations as well as for the need of continuous adjustments during the production ramp-ups.

All the efforts in reducing the average setup times are doomed unless there is an effort to deploy and co-ordinate the production process planning with the SMED teams. Accordingly, after adequately training all personnel involved in SMED operations the SMED teams were organized around the different modules/sections of the shop floor.
Taking into account the type of equipment and the modules/sections of the production departments, it was recommended to organize the SMED teams following a matrix organization. Those teams were led by experienced SMED team members of the different modules/sections and reported to the production manager.
All improvement efforts were focused on improving setup times and with this type of organization the production manager deployed all the resources and teams involving the different sections of the shop floor. Following this matrix organization the production manager controlled the SMED procedures as well as the setup times right after the involvement of a SMED team.

After the implementation, and taking into account a longer time frame as well as the operational and deployment stages, it was recommended to top management to define a brand new organizational structure that involves production planning, production process control, maintenance, quality and SMED teams. With the acquisition of new technologies to improve even further the results achieved, a new solution is to be analyzed by the top management level as it will also involve the definition of new setup times, new production layouts, new production schedules, new training and new SMED procedures. This was expected to be achieved in one year's time.
Finally, and after the production manager has succeeded in operationalizing the SMED teams, the introduction of quality and maintenance management continuous improvements in the modus operandi of the SMED teams will be highly recommendable in order to achieve better goals.

Conclusion

The development of this project enabled a thorough setup diagnosis within ALFA, which underpinned the identification of critical points and their solutions.
In this project the importance of setup time reduction was presented using SMED methodologies.
After implementing the SMED methodology, it is possible to defend that simple process-based innovations, as the separation of internal from external operations and the conversion of internal to external operations, are among the key drivers to productivity improvement.
The main purpose of the case study was to decrease the setup times of the three groups of machines in ALFA. The reduction of the setup times allowed to reduce the wastefulness in 362 960€, which represent about 2% of ALFA's sales Volume.
Clearly, in times of relentless competitiveness, process

innovation can be an extremely useful tool towards managerial success.
An important aspect that was not explicitly addressed was organizational innovation, which was always embedded in the process innovation. Thus, future work needs to highlight the flexibility of the SMED teams, the need to use a knowledge-based approach to properly disseminate the SMED methodology within the company, the consequences of SMED in the design of new machinery and the inventory reduction of the firm.

Another aspect that deserves a deeper analysis is the comparison of results among Ibero-American and Japanese companies in order to compare the potential of process and organizational innovation between those two types of firms.

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