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# Waste reduction by linear programing optimizing

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# Waste reduction by linear programing optimizing

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**Abstract.** The global economic crisis forces many industrial companies to be more concerned in reducing unnecessary cost, and eliminating all possible wastes inside the production lines. So that, most of companies focused on adopting the lean production tools [1]. The core idea of lean manufacturing is actually quite simple; relentlessly work on eliminating wastes from the manufacturing process. These wastes have a direct impact on costs, and profit [2]. Real-life problems can be modelled as linear programs. Linear programming is a problem-solving approach developed for situations involving maximizing or minimizing a linear function subject to linear constraints that, limit the degree to which the objective can be pursued. The objectives of this paper are to develop methods to reduce the waste in the different manufacturing processes in a technical support unit of Airplanes. This paper focuses on developing a linear programming approach in order to reduce the waste of material used in the production line. Single Minute Exchange of Die methodology (SMED) was implemented in order to reduce the changeover time. The achieved results showed that the linear programming is an effective and cheapest tool in optimizing the waste in the production lines.  By using linear programming, the organization can reduce the wasted materials from 15.1% to 6.6%, with annual costs saving 288,480 Egyptian pounds (EGP). The achieved results from implementing a simple lean production tool such as, SMED helps the organization to reduce the changeover time by 44%, with annual costs saving 29,440 EGP.


**Key words**: linear programming, lean production tools, SMED methodology.

## 1. Introduction

Nowadays, due to the national and the global economic crisis industries and companies, especially the manufacturing organizations, have either downsized or gone bankrupt, which forces industries to be more concerned in reducing unnecessary cost by eliminating any possible wastes. The basic concepts of lean production are eliminating all types of wastes from the manufacturing process. These wastes have a direct impact on costs; which considered a non-value adding operations. Raw material costs have edged up over the last few years and throughout 2011. Reducing material waste means greater resource efficiency and more profits. Each pound saved on raw materials costs goes straight to the bottom line, and that push organizations to adopt the concept of management science. Organizations are looking for structured, logical evidence-based ways of making decisions rather than relying solely on personal experience and gut-feel.

Linear programming (LP) is one of the simplest ways to perform optimization. It helps you solve some very complex optimization problems by making a few simplifying assumptions. As an analyst

you are bound to come across applications and problems to be solved by Linear Programming. Integer linear programming is an approach used for problems that can be set up as linear programs, with the additional requirement that some or all of the decision variables be integer values. Moreover, the technical support unit of Airplanes feeding industry with different manufacturing parts with minimal costs, and time consumption. Then, the technical support unit try to use the application of linear programming to reduce the percentage of waste in the used materials, also try to reduce the changeover time by implementing the SMED methodology. These very strict requirements are creating a lot of problems, as it means additional time is needed for setup. Changeover means machines are down which means the organization is wasting resources.

In 1985 Dr. Shigeo Shingo introduced his methodology called Single Minute Exchange of Die (SMED) [1]. SMED is a scientific approach to setup time reduction that can be applied in any factory and also to any machine [1]. The ultimate goal of SMED is to perform machine setup and changeover operations in less than ten minutes. Implementing SMED system leads to key improvement as Shingo mentioned [2]. This paper started with define and assessing all types of waste in technical support unit of Airplanes which summarized in material waste in the sheet metals, and waiting time waste due to changeover in the press station. Linear programing software is used to minimize the wasted materials, and SMED methodology is used to minimize the waiting time waste. The achieved results showed that the wasted materials is reduced from (15.1 to 6.6)%, and , the changeover time is reduced by 44%.

## 2. Describing the methodology

This part will propose the solution methodology to achieve the significant minimizing the waste in the production line.

### 2.1. Lean production

The main objectives of lean production system are continuous improvement of processes and cost reduction through the elimination of waste. The concept of waste (Muda in Japanese) is defined as any activity that does not add value to the product in the customer's perspective. [3] Considers seven types of waste: overproduction, inventory, waiting, defects, over-processing, motion and transportation. Lean Production provides a set of tools and techniques that can be applied to reduce those wastes, namely SMED, 5S, visual control, standard work. According to concept of LP, implementing its tools and techniques help minimize such wasted effort [4].

### 2.2. Kinds of waste

The main objective of the lean philosophy is eliminating all kinds of waste within a company's process [5]. The eliminated wastes will further expose other wastes and quality issues within the system. The seven types of wastes in lean manufacturing are considered as the following [6]:

   A. Overproduction: producing too much or too soon which results in poor flow of goods and increased inventory.
   B. Defects: problems in the product quality, poor delivery of products, or paperwork errors.
   C. Inventory: storing finished products or raw materials may incur unnecessary expenses.
   D. Over processing: using complex tools, or procedures, when simpler ones could produce the same output with the same efficiency or more.
   E. Transportation: excessive movement of people, goods, and information.
   F. Waiting: inactivity causes poor flow and increases the lead time (the time between the initiation and the completion of a process).
   G. Unnecessary motion: bending, reaching, or walking long distances to perform a task, caused by poor ergonomics.

### 2.3. Single Minute Exchange of Die (SMED)

Reducing Changeover Time is defined as the period between the last good product from previous production order leaving the machine and the first good product coming out from the following

production order [7, 8]. An experimental implementation of SMED can save about 2% of the company's sales volume (360,000 €) [9]. The safety of workers can be enhanced by applying SMED [10]. Implementation of SMED method in an automotive battery assembly line achieved reduction in setup time by 35% [11]. Another suggestion for conventional SMED method can bring about a great reduction in setup time of the bottleneck machine to the stamping production line [12]. Implementation of conventional SMED achieved more than 35% reduction in the setup time in an automotive battery assembly line [13]. Single Minute Exchange of Die or SMED system was developed by Shigeo Shingo, who was an industrial engineer consulting with Toyota. The methodology was about examining all setup operations and modifying the setup process to reduce the overall time and built on four main concepts [14]:

   A. Identify external tasks and internal tasks. External setup is the changeover operations that can be done while the machine is running; such as; getting all of the tools and equipment ready before shutting down the machine. Internal setup are operations that are internal to the machine, which means that the machine has to be off so that the tasks can be made, and that are mainly for the safety of the operator, machine and the product .

   B. Determine if any of the remaining internal tasks can be improved, so they are done as external tasks, such as pre-assembly elements or tooling, and reduce the required time to do those tasks .

   C. Simplify the remaining internal tasks. Use fixtures, locating pins or visual marks to speed up the required time to get the new parts .

   D. If possible, perform the internal tasks in parallel. If two operators can perform tasks at the same time, the time can be reduced without increasing the number of workers required for the setup process .

SMED includes the following procedures:

   A. Data collection and current state documentation. Developing a detailed process map and timing diagram is a good way to start the SMED analysis. Video recording also provides a valuable view of what actually happens during the changeover. Spaghetti charts can be used further to highlight opportunities to reduce the time operators spend walking, and relocating tools and parts. A value stream map provides insight into where SMED can have the biggest benefit.

   B. Activity classification; In this step activities are divided into two groups: the internal and external ones. External activities are all the set up activities that can be performed while machine is in operation. Internal setup activities are the ones that can be performed only if the machine is not in operation.

   C. Converting internal setup to external setup; Transforming internal into external activities as much is possible. It is the most efficient procedure ever for decreasing machine idle time.

   D. Standardization of the SMED procedures.

### 2.4. Linear programming

Linear programming was developed during World War II, when a system with which to maximize the efficiency of resources was of utmost importance. New war-related projects demanded attention and spread resources thin. According to [15] linear programming models are always used in to solve industrial problems include the use of scare resources, and maximizing the profit. Two linear programming models are formulated by [16] where one of them maximizes the revenue of a company and the other minimizes the cost of operation respectively. An application of linear programming model is achieved to maximize profit in a local production company [17]. Linear programming plays an important role in improving management decision; it has proven to be capable in solving problems such as production planning, allocation of resources, inventory control [18]. Linear programming has given mankind the ability to generate goals and to lay out path of detailed decision to take in order to achieve its goals when faced with practical problem of great complexity.

The LINGO software is a comprehensive tool designed to make building and solving linear optimization models faster, easier and more efficient. LINGO provides a completely integrated package that includes a powerful language for expressing optimization models, full featured environment for building and editing problems, and a set of fast built-in solvers [19].

## 3. Implementing the methodology

This work start with assessing the waste in all stations inside the production line and categorize them into two categories material waste and time waste. This methodology used linear programing for minimizing the waste in metal sheets, and also, used SMED to minimizing the wasted waiting time.

### 3.1. Waste assessment

In manufacturing, the types of waste that can be identified at each workstation vary, depending on the layout and the operation conducted at each station. In technical support unit of Airplanes, the stations are the sheet cutting station, where the sheet metal is cut into slide that, then, moves to the press station, where press machines either cut or form a component from the slides. When the needed components are done, they are joined in the welding station. Finally, the last station is the painting station before moving the final product to the stores. The production line layout is shown in figure 1.

Pareto chart is one of the seven quality tools was used to estimate the priority of each wasted area. The six areas and their total frequencies were collected in table 1. The obtained results from the Pareto chart showed that there are two important types of waste affecting the system with 80%, which represents 20% of the total number of wastes, as shown in figure 2. The two types of wastes that affect the production line are defects and waiting time.
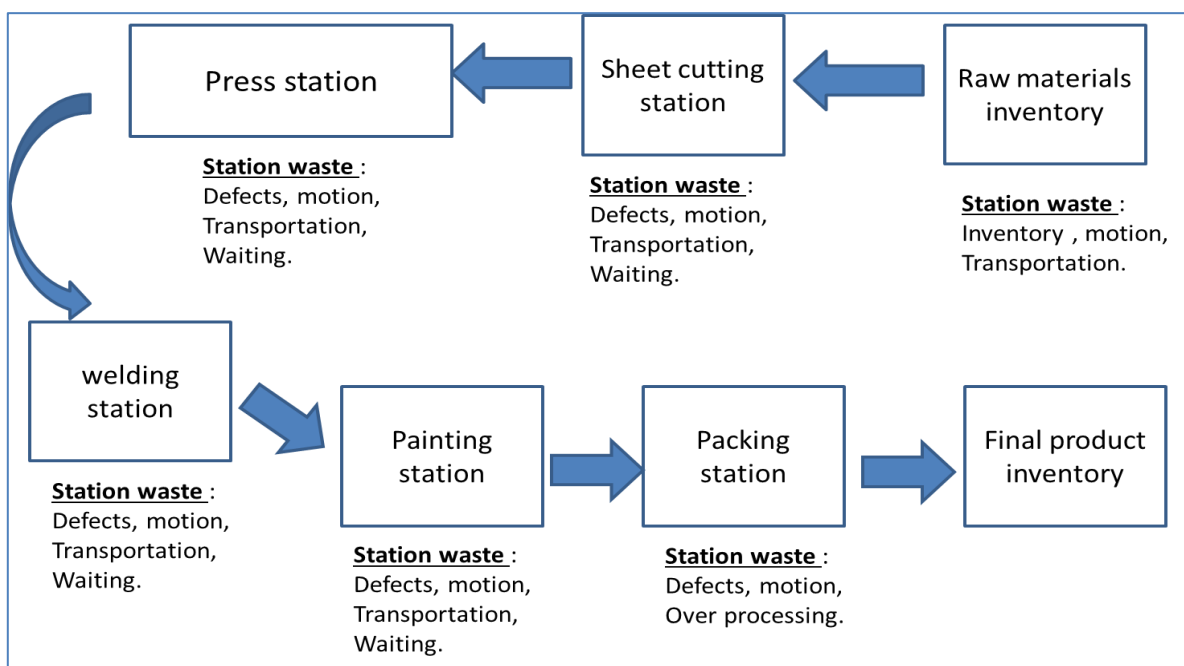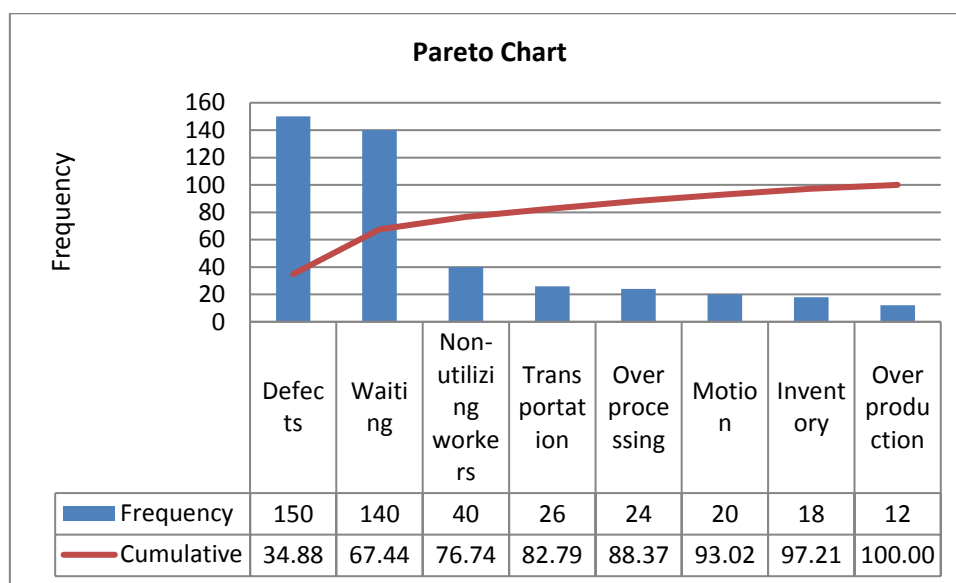


**Figure** 1 Kinds of wastes in the production line

**Table 1** The six areas of wastes and their total frequencies

| Waste | Frequencies | Percent % | Cumulative |
|---|---|---|---|
| Defects | 150 | 34.88 | 34.88 |
| Waiting | 140 | 32.56 | 67.44 |
| Non-utilizing workers | 40 | 9.30 | 76.74 |
| Transportation | 26 | 6.05 | 82.79 |
| Over processing | 24 | 5.58 | 88.37 |
| Motion | 20 | 4.65 | 93.02 |
| Inventory | 18 | 4.19 | 97.21 |
| Over production | 13 | 2.79 | 100.00 |
| Total | 430 | | |

**Pareto Chart**

| | Defects | Waiting | Non-utilizing workers | Transportation | Over processing | Motion | Inventory | Over production |
|---|---|---|---|---|---|---|---|---|
| Frequency | 150 | 140 | 40 | 26 | 24 | 20 | 18 | 12 |
| Cumulative | 34.88 | 67.44 | 76.74 | 82.79 | 88.37 | 93.02 | 97.21 | 100.00 |

**Figure 2.** Wastes areas in the production

The collected data about the wasted areas are achieved by using the mind mapping as a visual tool of thinking to give a clear image about the waste, then trying to reduce or eliminate them as possible. Waste can be material waste, time waste, motion waste or any non-value-added activities. Figure 3 and figure 4 summarize the six effective wasted areas in the organization and their sources that can be found in the production line. The achieved results from analyzing all types of waste showed that, two types of wastes are significant such that, material waste during cutting the sheet metal and the waiting time due changeover procedures in press station.

*3.2. Material waste*
Mind mapping defined that the material waste is been located in the cutting station which developed to cut the sheet metal into slides to be inserted on the manual control hydraulic press to produce different products. Each family of products is manufactured from a sheet metal with a specific sheet dimension. The plant is supplied with 27 different sheet metal dimensions to produce around 90 products and their subcomponents. The station capacity is 8 hours per shift, operated by two workers and a hydraulic cutting machine. The cutting processes achieved by cutting every specific sheet for one product only according to its dimension. That's mean, every sheet will cut in slides with fixed dimension and the reminder part length will be wasted material as shown in figure 5. Therefore, waste occurs in each sheet due to the sheet length can't be divided equally over the products slides length.
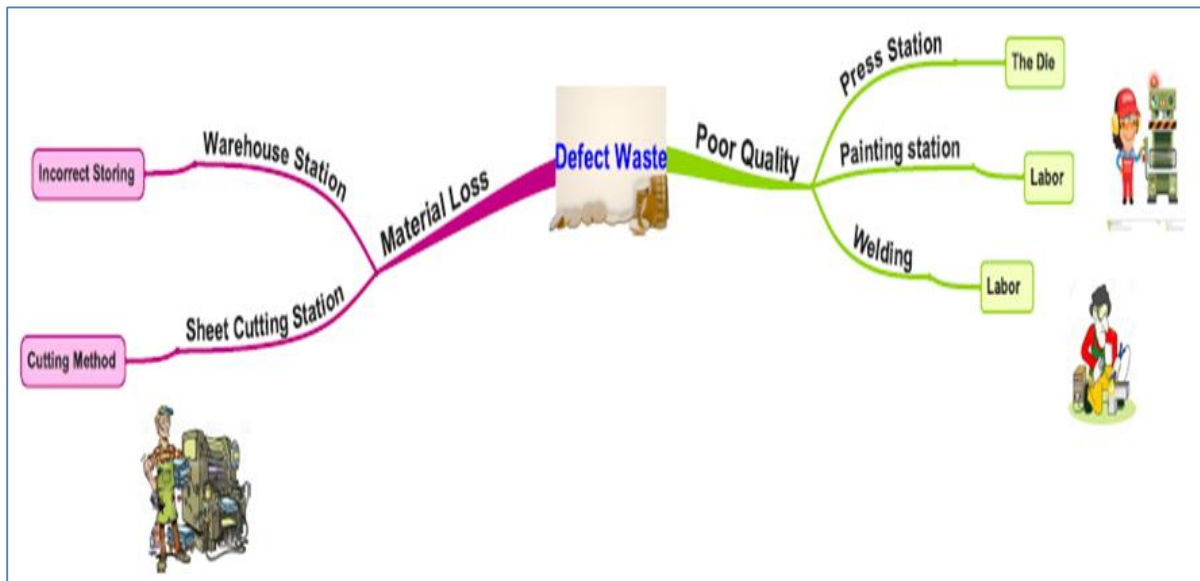
**Figure 3.**  Defect Waste Mind Map



**Figure 4.**  Waiting Time Waste Mind Map

Figure 5 shows a cutting pattern for product P50 and the waste produced. The collected data showed that the total material wastes in the sheets for cutting station are about 15.1 % from all kinds of used sheets. Figure 6 present the average monthly waste for different types of sheets. For example when use the 0.8 thickness cold iron sheet, then the resultant waste in the sheet will be 3.1 %.  By proper utilization of cutting the sheet metal, the wasted material in the cutting station can significantly improve the station efficiency and save capital investment.

| P50 |
|---|
| P50 |
| P50 |
| P50 |
| P50 |
| **Wasted material** |

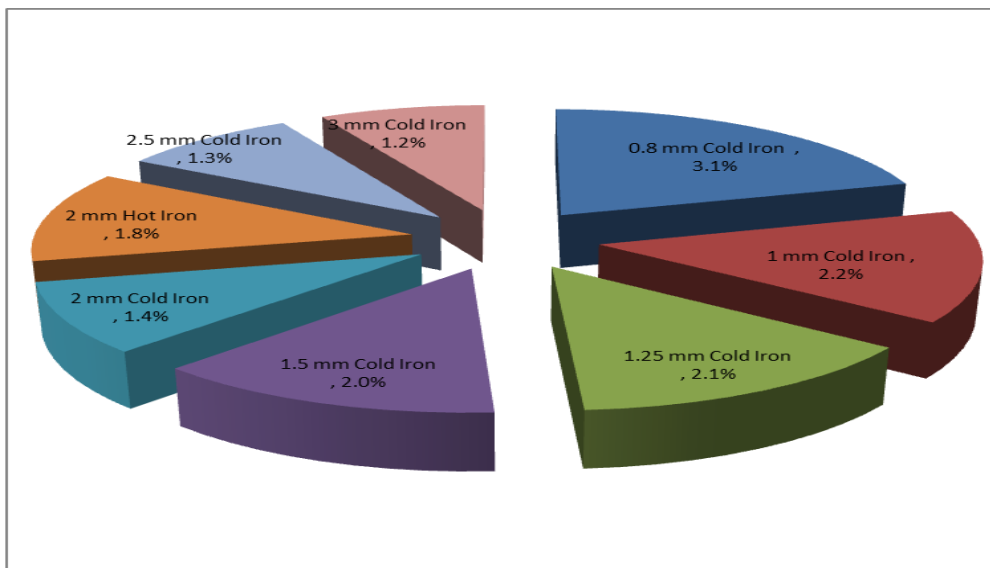**Figure 5.** Cutting Pattern for product P50



**Figure 6.** Percentage of waste for different types of sheets per month

### 3.3. Minimizing the waste by linear programming

Linear Programming is used in the cutting sheet stations to minimizing the wasted area during the cutting process in every sheet by changing the cutting pattern. It can be defined as the problem of finding the best way of cutting ordered items from stock rolls of length "L" such that, trim waste is minimized and the total demand is satisfied. The main advantage of linear programming methodology isn't, require any investment to implement it, the unit cost will be reduced.

### 3.3.1. The five steps of the integer Linear Programing.
Integer linear programming is a problem-solving approach developed for situations for maximizing or minimizing a linear function subject to linear constraints that, limit the degree to which the objective can be pursued, with assumption that all of the decision variables be integer values. There are five main phases for the integer linear programing methodology which are:

**Phase 1: Defining the problem**

It usually takes imagination, teamwork, and considerable effort to transform a rather general problem description into a well-defined problem. The problem was defined as due to the variety of the product

that can be cut on the same sheet type; the factory gets a standard one sheet dimension. Therefore, cutting one type of product causes a waste in the sheet, combining different types of products on the same sheet will reduce the waste.

**Phase 2: Model development**

This is the most important step in the integer linear programing model, as it represents the problem mathematically, describing the objectives, constraints, and other relationships that exist in the problem. The Standard Cutting Stock Problem is modeled by cutting stock rolls of length L into slide of length Li, aiming at satisfying the demand Di for each one of these N items. The mathematical model for minimizing trim-waste can be stated as follows:

$$Objective: Minimize\ Waste(j) = L - \sum_{i-1}^{N} Li \times Dij \qquad (1)$$

$$subjected\ to: \sum_{i=1}^{N} \sum_{j=1}^{S} Dij \geq Di \qquad (2)$$

$$\sum_{i=1}^{N} \sum_{j=1}^{S} Dij \geq 0 \qquad (3)$$

$$265 - \Delta min < L_{Sheet} < 265 + \Delta max; \qquad (4)$$

i ……. The product number.
j ……. The sheet number.
L ……. The standard length equal to 265 cm.

The objective function (1) minimizes the sum of trim waste for each blank. The optimal cutting pattern for each of the blanks is defined by decision variables $D_{ij}$ in (2). Depending on the given particular project, the decision variables (3) is an integer variable. The deviation of optimal length of blanks from the standard length is given by the relation $\Delta min$, and $\Delta max$ in equation (4). The formulated in this way combinatorial optimization task can be solved by means of any optimization solver, which will be the lingo solver in this paper.

**Phase 3: Data preparation**

The sheet metals are supplied with a predetermined length; these sheets are used to cut out elements that differ in size and number that are specific for each particular project. The model is believed to be used on ten supplied sheets. The supplied sheets and the components being cut from 27 sheet, ten sheets are cuts for more than two products .

**Phase 4: Running the model**

Using the LINGO, the model was solved to obtain the optimal cutting patterns to minimize the waste in the sheets. This model results were used for two months to verify that the model is reducing the waste and the needed sheets for production.

**Phase 5: Report generation**

By using the linear programming model, the organization can reduce the waste in the different sheets. The generated output of the program list some important information, such as, the needed sheets, the overall waste, each sheet's waste, and the products being cut from the sheets with their quantities. The waste per sheet for all types of sheet after implemented the model solution.

In the early implementation, a guide report, shown in figure 7, was attached with the numerical report generated by the Lingo Solver, to lead the worker through the report. The report defines the sheet length, the slide length, and the slide quantity in each sheet .The other sheet, shown in figure 8, was used to guide the worker through the cutting procedures. This sheet gives more understanding of the cutting approach, also the program used to generate a visual report. Those sheets are attached with the numerical report, and given to the worker to determine his understanding of the given data to cut sheets correctly according to the data given. Therefore, the worker error will be reduced.
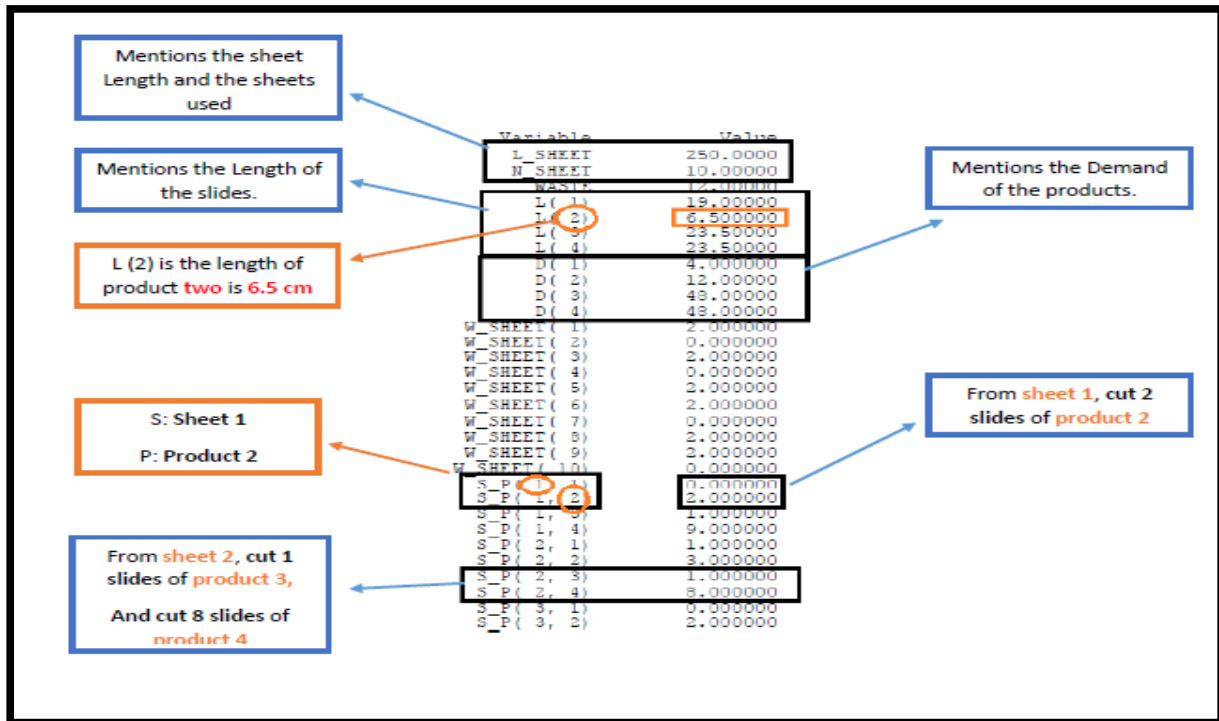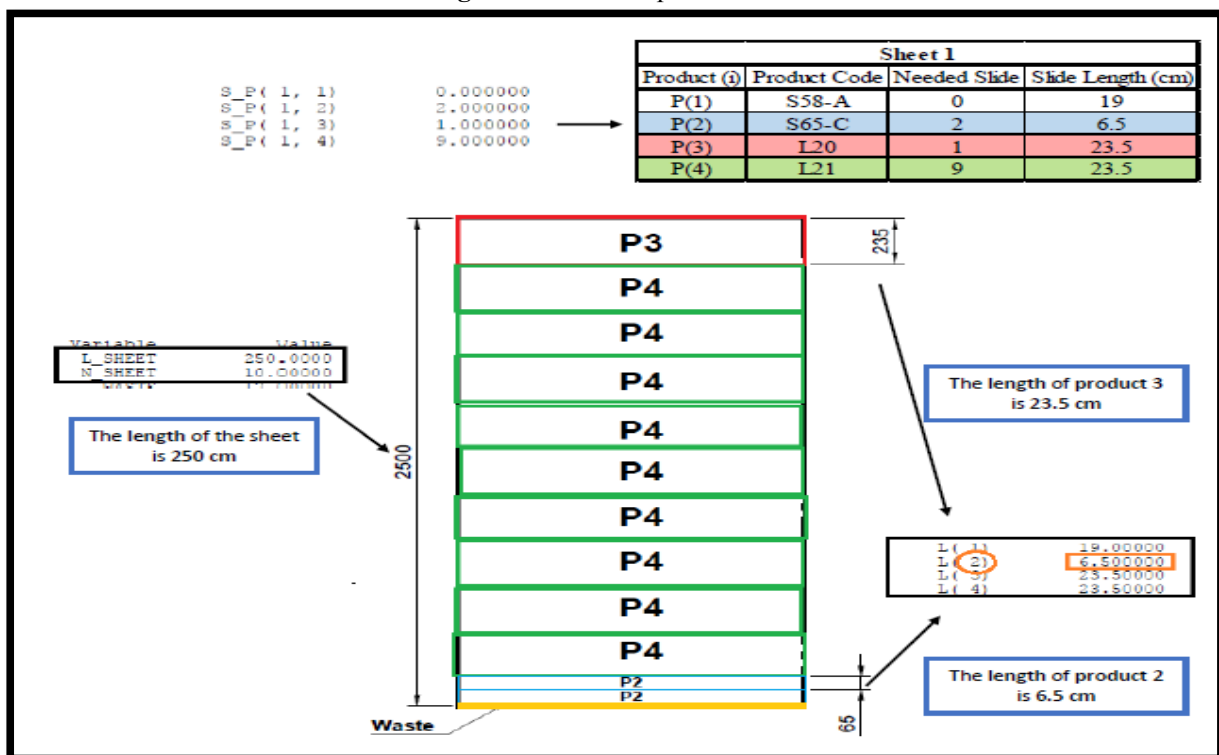
**Figure 7.** Guide report I



**Figure 8** Guide report II

### 3.4. Waiting time Waste

The obtained results from collected data for the waiting time showed that, the waste is the time consumed during machines setup in pressing machines station. Then by reducing the changeover time in the press station, it will reduce the manufacturing lead time. The press station is developed when the sheets are cut into slides. There are three main types of dies that can be clamped on both types of the press machines. A cutting die that is used to cut shapes on the product, the second die is forming die, which is used to form the sheet without cutting any material from it, the third type is a drilling die, which is used to drill holes in the sheet metals. The changeover in this station happens between each operation, the steps and the times of the changeover are represented in table 2.

The changeover was observed by listing and timing all the elements done by the worker during the setup process, there were some basic elements that need to be reviewed: planning, working method, and tooling. There are four main steps for the SMED methodology: the first step to define the changeover procedure, the second step is identifying the internal and external tasks, the third step is to convert internal setup to external setup. The final step is streamlines the internal tasks and standardize the Steps. By analyzing the changeover procedures, it was outlined that there are ten steps that are made sequentially causing in 45.5 minute to change a die in any of the working press machines.

### 3.5. Minimizing the Waiting time Waste by using SMED Methodology

The time taken for setup a press machine is around 45 minutes and most of the press machines make an average of 80 changeovers per month, which reduce the machine availability.

Identify the internal and external tasks are the most important step in the implementation of SMED. All activities have to be classified as external or internal based on whether they can be performed while the machine is working or not. Table 3 shows the classification of changeover tasks. All these tasks are done by two workers. In order to convert internal setup times to external setup times, the main focus was on the tasks related to material handling, information gathering, cleaning and adjustments. In the current state, there are only three tasks out of ten tasks can be done while the machine is working.

These external tasks will be removed out of the changeover window. The achieved results showed that 70% of the tasks are internal tasks and due to safety issues such as all the activities related to the press piston have high risk for employee who adjusts them when the machine is running, then, it will be difficult to convert them into external tasks as shown in table 3. But, other aspects have been applied, such as the movement of the workers during performing these tasks and worker utilization. Streamline the tasks means to remove unnecessary activities during the setup time, such as movement or searching for the tools. In the current state, after the worker finishes the last piece, he orders to change the die. The operator who tends to make the changeover requests the forklift, which takes about 20 minutes to respond. It is believed that these 20 minutes can be completely moved out of the changeover step by providing equipment that will operate only for the changeover task. Also, the operator will be asked to request the before the changeover by 10 min.

## 4. Results

The achieved results from implementation of linear programing in the process showed that the total waste of materials reduced from 15.1% to 6.6%. This reduction means capability of producing more products from the same number of sheets. The percentages of waste before and after implementing the linear programing solution are presented in figure 9. Table 4 shows the excess number of product produced and the average cost saving for each sheet. The changeover time was reduced by 44% after implementing the SMED methodology, which reduced the worker overtime by 26.6 Hrs. per month; it takes a minimum of 48 workers to operate the line during overtime shift. The total annual saving from change over time is 29,400 EGP as shown in table 5.

**Table 2.**   Changeover Procedures

| Step | Activities | Time (min) |
|---|---|---|
| | Setup Analysis Sheet | |
| 1 | Adjusting the piston so that the bottom part of the piston head and the upper part of the die are in thread. | 0.7 |
| 2 | Searching for the tools needed to set the new piston path. | 2 |
| 3 | Disassemble the screws which used to fix the die at the top and bottom | 4 |
| 4 | Raising the head of the piston which is responsible for movement and formation to the highest point. | 0.8 |
| 5 | Requesting the forklift labor to come to carry the die and waiting him. | 18 |
| 6 | Forklift carries the die and put it in the store in the place assigned to it. | 2 |
| 7 | The Clark then brings the needed die to be fixed on the piston body. | 4 |
| 8 | Adjust the required path and lower the top of the piston so that the top and bottom of the die are in thread. | 2 |
| 9 | Install and adjust the die in the correct place. | 4 |
| 10 | Turning on the piston, conducting practical experiment, testing the resulting product and its conformity to specifications | 8 |
| | Total time | 45.5 |

**Table 3** the new changeover procedures

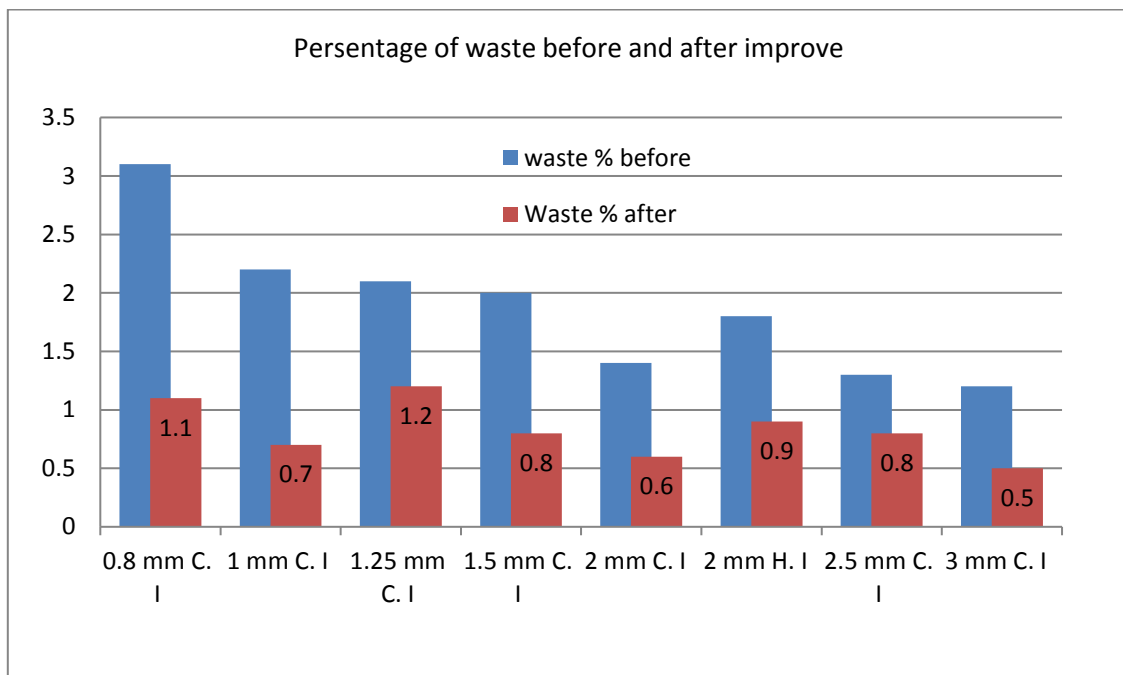| Step | Changeover Element | Actual time (min) | |
|---|---|---|---|
| | | Internal | External |
| 1 | Adjusting the piston so that the bottom part of the piston head and the upper part of the die are in thread. | 0. 7 | |
| 2 | Searching for the tools needed to set the new piston path. | | 2 |
| 3 | Disassemble the screws which used to fix the die at the top and bottom | 4 | |
| 4 | Raising the head of the piston which is responsible for movement and formation to the highest point. | 0.8 | |
| 5 | Requesting the forklift labor to come to carry the die and waiting him. | | 18 |
| 6 | Forklift carries the die and put it in the store in the place assigned to it. | 2 | |
| 7 | The Clark then brings the needed die to be fixed on the piston body. | 4 | |
| 8 | Adjust the required path and lower the top of the piston so that the top and bottom of the die are in thread. | 2 | |
| 9 | Install and adjust the die in the correct place. | 4 | |
| 10 | Turning on the piston, conducting practical experiment, testing the resulting product and its conformity to specifications | 8 | |
| Total | | 25.5 | 20 |

**Figure 9** percentage of waste before and after implementing the solution

**Table 4** Materials and costs saving

| Sheet thickness | Excess slides/ Month | Excess slides/ Year | Annual saving (EGP) |
|---|---|---|---|
| Sheet 0.8 mm | 80 | 960 | 24000 |
| Sheet 1 mm | 35 | 420 | 16800 |
| Sheet 1.25 mm | 55 | 660 | 44880 |
| Sheet 1.5 mm | 60 | 720 | 57600 |
| Sheet 2 mm | 85 | 1020 | 81600 |
| Sheet 3 mm | 50 | 600 | 63600 |
| Total annual saving | | | 288,480 |

**Table 5** The total annual saving from change over time

| Saving time/ changeover (Hrs.) | Changeover/day | Saving time /Month (Hrs.) | The cost for operating Hr. /person (EGP) | Annual saving (EGP) |
|---|---|---|---|---|
| 0.33 | 4 | 26.6 | 23 | 29,440 |

## 5. Conclusion

The objective of this paper is to reduce the waste in the different manufacturing processes in a technical support unit of Airplanes by using lean production tools. One of the wastes is generated from the sheet cutting process, in which the sheet is cut into specific pattern of one product type, which leads to a huge waste of material. Also there are more wastes of time in the setup of seven grouped press machines that used for manufacturing the variety of products, which has a huge impact on the machine availability. This paper presented a simple and accurate method for minimizing the waste in the sheet metal during the cutting operation by using linear programing approach, in which the waste was reduced from 15.1% to 6.6% without any cost, and with total annual saving 288,480 (EGP). This paper implemented a simple lean production tool for reducing the changeover time by using Single Minute Exchange of Die to reduce the changeover time by 44%, with annual saving 29,440 (EGP).

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