KEYWORDS Lean manufacturing aerospace wastes

WASTE MEASUREMENT PROJECT OF AN AERONAUTIC ASSEMBLY LINE

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ABSTRACT

Over the last two decades, the Lean philosophy is gaining significant ground in different industrial sectors beyond the automotive one. Besides presenting particular characteristics, large aircraft manufacturers have started using Lean concepts aiming to optimize the manufacture projects of their products. This article aims to discuss the application of the Lean philosophy in the aerospace sector, as well as measure the main waste that occurs in a real company in this sector, using a case study. At the end of this study, some tools used to analyze collected data, as well as some upgrades, will be discussed.

1. Introduction

The premise "high quality and productivity associated with low cost", which until recently has sounded like an example of ambiguity, is now the key to success for companies in the aeronautic sector *(CRUTE et al., 2003)*.

Reputable companies, in which the investment in a single product is high, with long cycle times and consequently, with a low value of an individual operation, the detection of activities that add value or do not add value, as well as waste elimination, were not the subject of improvement projects in the aeronautical sector as structured over the past fifty years.

After the publication of the work: "The Machine that Changed the World", in 1990 *(WOMACK, JONES & ROOS, 2004)*, the lean philosophy became more popular in different industrial sectors beyond the automotive one, and the manufacture has been modifying greatly. Waste elimination, which leads to a reduced lead time, increases the product quality and reduces costs *(WOMACK, JONES & ROOS, 2004)*, is now being increasingly desired by the aerospace sector.

Nowadays, mass production is giving way to different market requirements. According to Crute et al. *(2003)*, the following terms represent the new industrial age, which also fall into the aerospace sector.

- Mass Customization, where the volume is connected to individual customer needs;
- Flexible Specialization, related to company participation in only part of the product value chain, a fact which meets the vertical integration of production proposed by Ford (GRANDIN, 2010);
- Agility, since the company should change its goals quickly according to market demands;
- Strategy, always aiming at the search for better production practices;
- Lean Manufacturing, developed from the Toyota Production System, and used as a mean to achieve consistent answers to the above terms.

For decades, due to low competition and large time cycles, the aerospace sector has not focused on waste elimination and studies of the activities that add or do not add value to the assembly of a particular product. However, this scenario is changing. Large companies in this sector, such as Boeing and Lockheed Martin, are using the Lean philosophy and achieving satisfactory results.

According to Joyce and Schechter *(2014)*, the results of applying the Lean philosophy in the production of the American Lockheed Martin's aircrafts F-16, F-22 e C-130, have been so satisfactory that supporting areas of the whole company, such as Financial and Human Resources, are being targeted with the same philosophy.

Boeing, through the Lean Production, aims for challenging goals, such as increasing the quality in 90% of all its production lines and drastic reduction of costs *(AW&ST, 2010; CRUTE et al. 2003)*.

This study aims at the measurement of the main wastes that occur in a specific production line of aeronautic sector and following classification according to their impact. It is expected to mention possible improvements.

The theoretical foundation about the Lean Philosophy, research methodology, result analysis, conclusion and bibliography will be presented in the following paragraphs.

2. Lean manufacturing

Hardly anyone related to the industrial sector has not heard expressions such as: Lean Manufacturing, lean or lean thinking. Despite the fact that these concepts are recent, they date back to the Toyota Production System *(TPS)*, which emerged in the 1940s in Japan by Taiichi Ohno. This system is grounded on the desire to establish a continuous flow production, without waste and with high efficiency. The TPS was also based on the premise that a single operation or activity influences the added value for the end customer *(BEINTINGER, 2012)*. This methodology was the opposite of the one used in the West, where mass production and the Material Requirement Planning *(MRP)* had focused on high productivity and reduced purchasing range of options *(GRANDIN, 2010)*.

However, after the 1990s, with the publication of Womack's first work, the lean philosophy earned permanent space outside Japan and started to develop in different industrial sectors and areas.

In 1996, Womack and Jones *(1996)* published Lean Thinking: Banish Waste and Create Wealth in your Corporation, which is also a landmark in the philosophy consolidation, since it developed an action guide for its implementation, which also shows that it is not a philosophy or a set of tools applicable only to the automotive sector.

Focus of Lean Production

Lean Manufacturing consists of a set of socio technical practices aimed at the elimination of waste that occurs in the production chain of a given good, bringing benefits to the corporation and to the end customer *(FURLAN, VINELLI & DAL PONT, 2011)*. According to Manfredini and Suski *(2008)*, the benefits achieved are: Cultural Homogenization of operators, inventory reduction, improved product quality, lead time reduction and consequent cost reduction and increased end customer satisfaction.

According to Rother and Shook *(1990)*, lean production is a set of best practices that cross departmental boundaries whose aim is to eliminate waste and create value. The production activities can be divided into three major groups:

- Value-Added Activities;
- Required Non-Value-Added Activities;
- Non-Value-Added Activities, and no longer required.

Figure 1 presents the participation of each major group of activity.

Note that Non-Value-Added activities represent 95% of the total amount, with 35% of activities from the group 2 and 60% of activities from the group 3.

Rother and Shook *(1999)* state that the focus of Lean production are the activities from groups 2 and 3. The activities from group 3 are no longer required, and they should be eliminated immediately, while the activities from group 2 should be eliminated as soon as possible from to the companies.

Figure 2 presents the difference between the focus of Lean and Mass Production.

Waste Classification

Waste is any action, or lack of it, that does not add value to the final product. According to Ohno *(1998)*, there are seven major types of waste, which have been originally designated as mudas, which might represent 80-95% of the time and cost of the production process.

Arantes *(2008)* and Ghinato *(2000)* sort the seven types of waste in a clear and simple way. The first group of waste are the losses generated due to overproduction which are the most damaging, since they have the property of concealing the others, and can be divided into two subgroups. The first subgroup are the losses due to overproduction by quantity, which occur when the production is performed over the programmed quantity, thus, the products will be stored while awaiting the opportunity to be processed or consumed by further steps. The second subgroup are the losses due to overproduction by anticipation, which occur when the production is performed

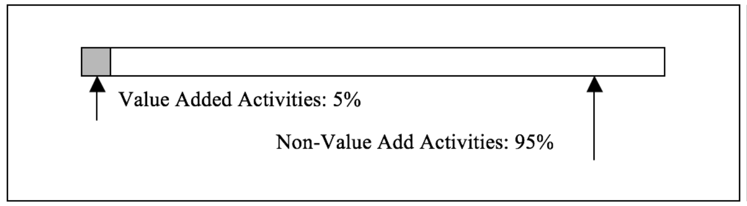

FIGURE 1. *Composition of activities according to Hines and Taylor (2000)*

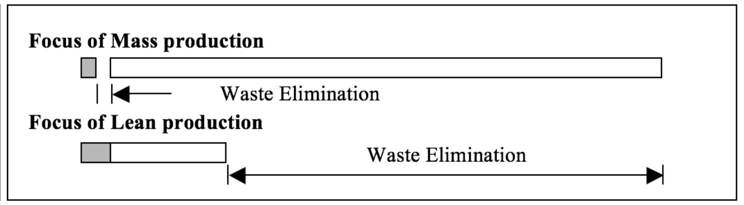

FIGURE 2. *Focus of Mass and Lean Production according to Hines and Taylor (2000)*

prior to the required time and, again, the products will be stored while the opportunity to be processed or consumed by further steps.

The second group of waste are is the losses generated due to waiting, which occur as unnecessary waiting, and can be divided into three subgroups. The first subgroup are the losses due to waiting to be performed, which occur when the upcoming lot must wait until the end of the processing being performed on the previous lot. The second subgroup are is the losses due to waiting for the lot, which occur when a product waits until the end of the processing being performed on the other products in its lot. The third subgroup are the losses due to waiting of operator, which occur when the operator remains near the machine to monitor the processing from start to finish.

The third group of waste are the losses generated by transportation and handling, which occur as unnecessary transport of raw materials, materials being processed, and finished products. The most significant improvements in terms of reducing the losses generated by transportation, are those obtained by eliminating the need for transportation. Therefore, the improvements of transport equipment should be introduced only if there is no possibility of eliminating the need for transportation.

The fourth group of waste are the losses generated by over processing, which occur as unnecessary processing that does not add value to customers. The most significant improvements in terms of reducing the losses generated by over processing are those that eliminate non-value added activities. Thus, improving the value-added activities should be introduced only if there is no possibility of eliminating non-value added activities.

The fifth group of waste are the losses generated by inventories, which occur as unnecessary inventory of raw materials, materials being processed and finished products. Companies based on mass production use a gradual increase of inventory to conceal the problems, while companies based on lean production use the opposite, which means a gradual decrease of inventory to expose the problems.

The sixth group of waste are the losses generated by motion, which occur as unnecessary movements performed by the operators. The most significant improvements in terms of reducing the losses generated by motion, are those obtained through movement rationalization. Moreover, improvements in automation should be introduced only if there is no possibility of movement rationalization.

The seventh group of waste are the losses of producing defective products, which occur as manufacturing defective products, which means they do not meet customer specifications. The most significant improvements in terms of reducing the losses of producing defective products are obtained through systematic application of control methods in the root cause of abnormalities.

The comparative **Table 1**, proposed by Salgado et al. *(2009)*, contains the main causes of the seven types of waste cited above.

	Wastes	Causes
1	Over production	-Producing more than requested by customers. -Producing before ordered.
2	Waiting	-Materials and parts of coming operations -Maintenance -Tools -Operators - Queue for further operations
3	Transportation and Handling	-Excessive movement of parts, materials and products. -Storage movements
4	Over processing	-Process and equipment oversizing. -Unnecessary accuracy of product and process.
5	Inventory	-Overstock -Queues -Inventory between operations.
3	Motion	- Short-range movements, such as: To reach, to reorganize, to count and research.
7	Defects	-Products which do not meet required specifications - Material of which its origin is dubious.

TABLE 1. *Main causes of lean seven wastes. Source - Salgado et al (2009)*

Making a leaner flow

In order to get a lean flow, it is necessary to eliminate wastes following the idea that a process is triggered only when the next one needs. To get it done, Rother and Shook *(2003)*, suggest some steps to be followed.

- The first one is related to the takt time, which is the frequency a product or a part must be manufactured based on rate of sales, to meet customers' demands. In other words, takt is the division of available work per shift by customer demand (also per shift)
- Continuous flow should be prioritized, which means that a part or a material goes through a set of activities without being stopped. This is the most efficient production method. Establishing a continuous flow directly from pull systems might be difficult, however, it may be used during the intermediate stages, as combining some aspects of continuous flow with FIFO (First in, first out) and pull systems.
- Establishment of pull systems. When it is not possible to establish a continuous flow, pull systems should be established. It is the use of supermarkets through kanbans in order to give the exact production order to the previous process, without attempting to predict requests from the next process.
- Establishment of pacemaker process. Usually, this is the last process in continuous flow in door-to-door value stream, which means, from materials input to product output. After the pacemaker process, it is mandatory to have a continuous flow up to the finished products. The correct selection of pacemaker process will define which elements of the value stream will be part of the lead time from customers' orders to finished products.
- Leveling of production mix. Usually, there is more than one product being performed by the same process. However, what is the exact quantity of each product that should be produced in sequence? According to the Lean philosophy, producing several copies of the same product reduces the velocity of response to the market, and indirectly helps in creating inventories. On the other hand, the more leveled the production mix, the quicker the response will be to the customer market with short lead times.
- Leveling of production volume. When a rate of leveled production is established, a predictable production flow is created. When a short production volume is given to the pacemaker process, rapid corrective actions can be made to potential problems that may arise on the line.
- Developing the ability of making every part every interval (EPEI). Once tools' changeover time has been optimized, it becomes easier to produce smaller lots. EPEI refers to producing a single part within certain periods of time (days, weeks or shifts), which leads to a more predictable process and optimizes the response to the market.

It is noticed that items e, f and g should be carefully examined, since the optimization of a process that presents a fixed position layouts might be difficult in long cycle times and repetition of activities after long intervals.

3. Research methodology

This study is classified as exploratory, descriptive and quantitative. In order to achieve the study's objectives, the single case study method was chosen. The case study deepens the investigation into one or more objects in order to understand a phenomenon and its borders, suggests hypotheses, questions, or develops the theory *(MICHAEL, 2007; MURAD, LIMA & NETO, 2015)*. Yin *(1994)* states that the case study can be conducted when the researcher has no control and influence over the involved phenomena and when the research is focused on current events, which applies to the production line of the subject matter, an industry that has an aeronautic assembly line and belongs to an aeronautic group listed among the ten largest aeronautic groups in the world.

Procedure and Methods

In this stage, the process has been analyzed, the procedures have been defined and the part of a production line of a given product has been chosen. This line is responsible for most of the assemblies performed.

In this stage, in order to measure the waste, the fitters' daily shifts would be analyzed. Using a timer, released at the beginning of shift work, all activities performed by a given fitter had their start and end time recorded in a table. To simplify and standardize the analysis, the possible activities to be performed have been identified and classified as one of the waste types according to the lean philosophy, as shown in attachment 1. There is a possible classification for each identified activity: Value-Added, Required Non-Value-Added, or some type of waste.

The activities have been initially classified into two types: Value-added and Non-Value-Added. The latter ones, have been subdivided into two groups: Required and non-required activities. Waste name has been adopted for Non-value added and non-required activities.

The company's own data was used for the attachment 1 construction list, surveys have been sent to operators located at strategic positions in the assembly line, face-to-face interviews have been conducted and the routine of ten operators has been observed. Another important fact is that this list has been built to facilitate further data analysis, mainly through FTAs *(Failure Tree Analysis)*.

It is may be noted that the creation of "Idleness" waste has been necessary, since the line showed a high idleness rate. It is also noted that, due to the measurement that focused on operators' routine and their times, the waste "inventories" and "overproduction" have not been measured. It is noteworthy that developing idle activities represents a free choice of each fitter, which means they are not related to the assembly process or the context of work being analyzed. The defect waste has been measured according to the performed time to rework activities.

The categories of wastes "over production" and "inventory" were not included in this research, since they cannot be inferred by analysing workers' routines.

The AV and NAN fields were necessary, since not all activities are designated as waste and many of them are necessary every working day.

The add-value activities have been considered as assembly, schedule disassembly and schedule tests, because it is assumed that the end customer accepts to pay for those performed activities. However, it is possible that among the value added activities, there are some unnecessary, redundant, or non-optimized ones. However, since they are scheduled activities, according to analysis performed by the technical sector responsible by assembly, following the procedures has been considered as value added.

Waste Measurement

At this stage, the measurement of wastes present in the line has been performed. To get it done, besides the measurement of 10 shifts to build the attachment 1 list, there was initially a pilot measurement of the daily routine of 12 operators. With the pilot, it was possible to train the measurers and experience the method. The measurers were not aware that they were performing a pilot measurement.

After twelve measurements, the measurers had a meeting to perform a review and share experiences. Afterwards, there were real measurements. At this stage, the time of 24 randomly operators was measured, which resulted in 240 hours of measurements.

Another important factor is that six people played the role of measurers, which helped helps in the variability of the process, thus making it possible to reduce trending errors.

The measurement procedure was the Chrono analysis, which means that by using a stopwatch, the time of each new activity was registered. To do so, a similar table was used in attachment 2.

4. Results and analysis

Value Added

One full workday at the analyzed company is composed of 8.7 hours of work and 1.5 hours of break *(1 hour for lunch and two breaks of 15 minutes each)*. Analysis and results in this paper will take into account only work hours, in other words, one workday will be considered as 8.7 hours.

Annex 3 shows the results obtained during 24 trials. Times were classified into 3 categories: value-added *(AV)*, required non-value-added *(NNVA)* and wastes. Wastes were classified into the categories described in annex 1 *(see 'Legend')*. Standard deviations are high due to the difference among workers' activities. Low level of activities standardization cannot be stated because trials were not done on one single pre-defined task. Trials were made on an entire workday of workers who executed several kinds of tasks and activities.

Figure 3 summarizes the results in three main categories. Figures represent the average of percent times. During a workday *(8.7 hours)*, one worker spent about 58.2% of his time executing waste activities, about 12.3% required non-value-adding activities and 29.5% added-value activities.

All statements that compare means between and among groups in this paper are supported by hypothesis tests *(two sample t and one way ANOVA)* with 99% confidence.

The means of value-added activities required non-value-adding activities and wastes are different. In fact, wastes have the highest averages and value-added activities have higher averages than required-non-value adding activities.

Wastes

Figure 4 shows a Pareto Chart made from stochastic data extracted from Annex 3. This chart compares averages in each category of wastes per worker in a workday *(in minutes)*.

The averages in each category of wastes are different. Highest time averages can be found in the categories 'Idleness' and 'Over processing'. The group that holds the third and fourth highest averages is composed of 'Motion' and 'Defects'. The fifth highest averages are "Waiting'. The lowest averages can be founded at 'Transportation'.

Workers were not responsible for transporting material. This may explain the lowest averages of 'Transportation'. In fact, the company had another department responsible for logistic activities. It can be inferred that necessary materials for assembles were available near the workers.

With an analysis of annex 1 and figure 3, high values of 'Over Processing', 'Motion' and 'Defects' can be explained as:

- Workers waste time to understand how assemblies should be. The company should start a project in order to capacitate its employees and improve its documents;
- Workers waste time correcting assembly defects. If they had been more trained and the documents were easier and clearer, this time could be lower;
- Workers waste time to identify, look for and prepare material. Logistics departments should start a new project in order to improve this service and reduce these wastes;
- Workers waste time to take cleaning materials before applying 5S in their work place. These products should be more easily available;

Annex 4 shows the results obtained during 24 trials. Times were classified into the categories described in annex 1. **Figure 5** shows a Pareto Chart made from stochastic data extracted from Annex 4. This chart compares averages in each group of activities in minutes during one day per worker. Group A - operate - was not considered in this analysis.

The averages for each group are different. Highest time averages can be found in group I - unnecessary stops. It means a worker wastes approximately 1h49min per day executing activities such as talking, using cell phone, etc. The groups that have lowest averages are: group D *(looking for documents)*, group K *(unusual activities)* and group L *(support activities)*.

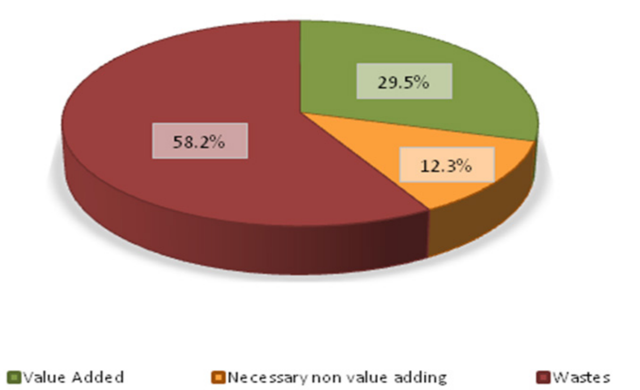

FIGURE 3. *Averages of VA, RNVA and wastes per worker in a workday (in percentages)*

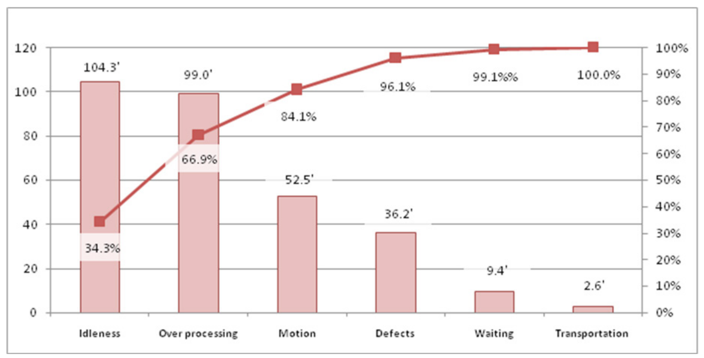

FIGURE 4. *Pareto Chart: averages of wastes per worker in a workday (in minutes)*

Root causes of the largest time activity

Figure 6 shows six FTAs *(Failure Tree Analysis)* together made from activity I *(unnecessary stops)* towards its root causes. Activity I was chosen because it had the greatest biggest average time among other activities *(except activity A - operate)*. Group I has six subcategories, each one with has an average time according to annex 1. Each category was considered as a failure mode and corresponds to an FTA. Average times were written on the top of the FTA.

Every event has a number at the bottom to identify it. At the its top, there is an estimated percentage of the relevance of this cause to produce the higher event. Percentages are the result of a consensus of all observers. When there is no percentage, it must be understood as 100%. Triangles were used to address a cause to another event in order to avoid repetitions in FTAs. Root causes are in circles. When there is more than one cause for each event, the symbol adopted can be understood as "or", in other words, it states that the event will occur if one or more causes occur, it does not need the occurrence of all events.

Table 1 shows proposed countermeasures for root causes. Average times for activities I in annex 1 and percentages of relevance of each cause at FTAs enabled the estimation of the measurement of how many minutes per day and per worker could be saved if a given countermeasure was successfully adopted. This estimated time was identified as Impact in **Table 1**. For each countermeasure, there is a Likert scale with a number between 0 *(low effort)* and 10 *(high effort)* in the column Effort. These values were estimated to quantify efforts to implement each countermeasure. They take into account costs, number of people to implement it and the time of the implementation.

Figure 7 shows the Impact x Effort Matrix for **Table 2**. The countermeasure of root cause 61 was hidden in this graphic.

5. Conclusion

This case study shows that there are fields to be explored with regard to the implementation of Lean Manufacturing, especially in sectors beyond the automotive one. In fact, in recent years, companies from the aeronautic sector have been concerned about this subject.

This paper presented a project of measurement of workers' activities in an aeronautic assembly line in order to suggest projects to increase the value added by reducing wastes. Initially, a timing of workers' workdays was done. Every worker spends about 58.23% of his workday executing waste activities and about 29.46% executing value added activities. However, the value added percentage may be smaller because assemblies are not optimized.

Among the kinds of wastes analyzed in this study, idleness and over processing had the biggest participation with approximately 1h44min per worker in a workday - 19.98% of the workday - for idleness and 1h39min - 18.97% - for over processing. However, idleness as waste is often ignored. Thus, one of the contributions of this paper is stating that idleness must be taken into account in waste analyses. As noted, idleness can waste a big part of the workday, but it can be very difficult to observe.

Through a Pareto Chart, a hierarchy of groups of activities that present the biggest time was done. Group I - unnecessary stops - had the biggest value. Through Failure Tree Analyses, countermeasures for root causes of Group I were proposed. The timing, FTAs and countermeasures enabled the estimation of the impact of each proposed countermeasure. The impact corresponds to the value in minutes per worker during a workday that could be saved if a given countermeasure was successfully implanted.

Each countermeasure was also associated with an effort concerned with to the difficulty to implement it. An impact effort matrix was built to guide the implementation of countermeasures. The main proposed countermeasure was training managers. Other countermeasures were creating projects to favor adaptation of workers and their families in the city and installing visual or audible alarms in the assembly line.

The importance of this paper can be seen in its real applicability in the analyzed company and also in its contribution to the literature. Before their publication, results were presented to managers and CEO of the group in order to guide them to choose projects to increase the value added in the assembly line.

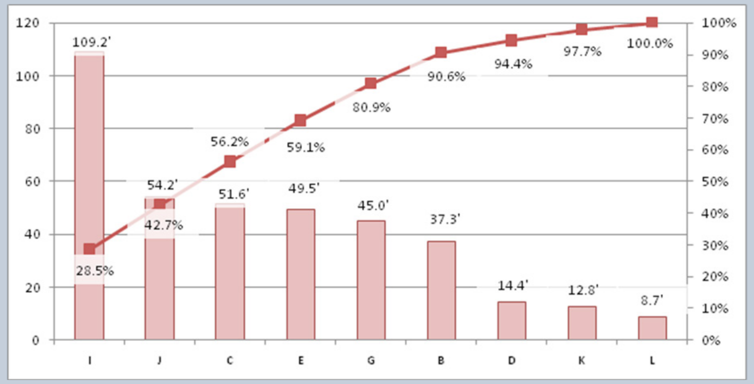

FIGURE 5. *Pareto Chart: averages of the groups of activities per worker in a workday (in minutes)*

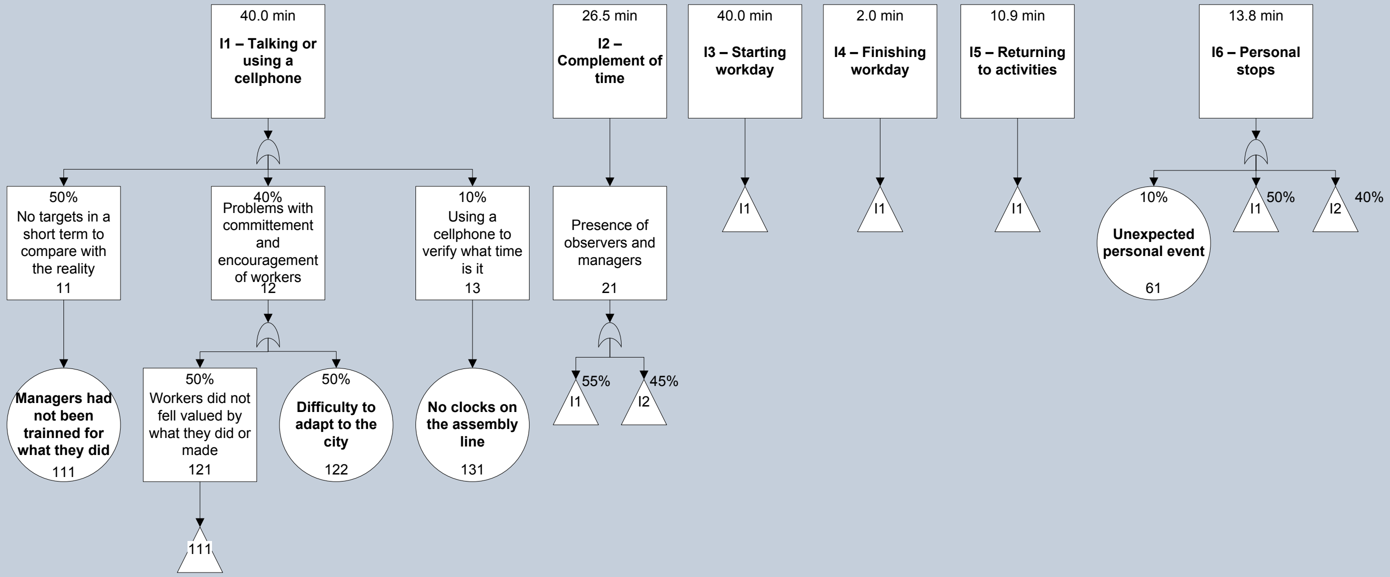

FIGURE 6. *Failure Tree Analyses*

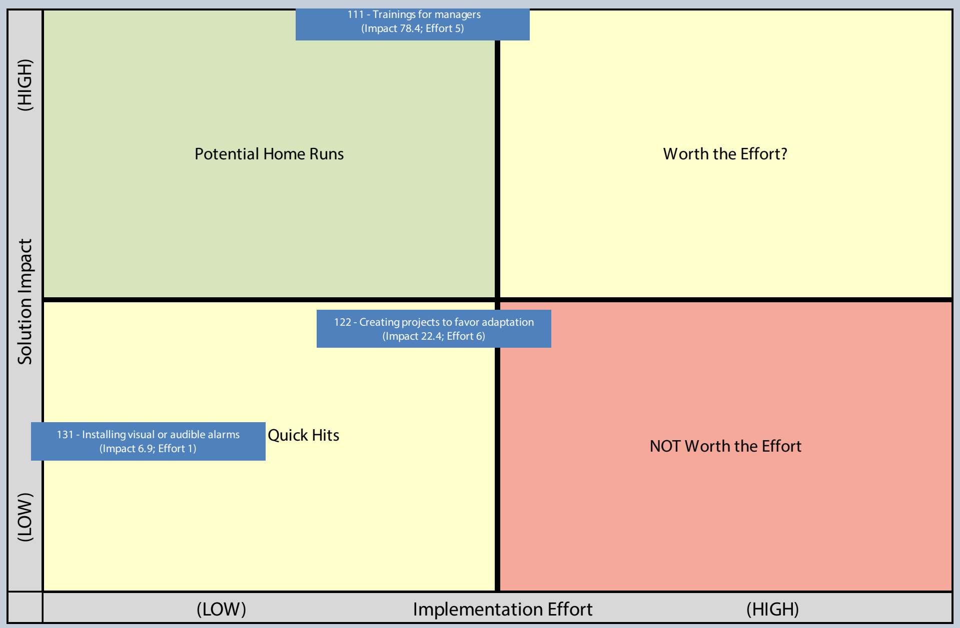

FIGURE 7. *Impact x Effort Matrix*

Root cause	Countermeasure	Impact	Effort
111	Training for managers	78.4	5
122	Creating projects to favor adaptation	22.4	6
131	Installing visual or audible alarms	6.9	1
61	No action - Accepting the problem	1.4	0

TABLE 2. *Countermeasures for root causes*

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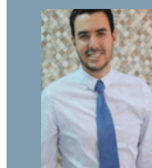

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ANNEXES
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