Six Sigma for workplace safety improvement: Improving hazards and unsafe conditions in a metallic packaging manufacturing company

Six Sigma has been applied as a business process improvement strategy in many companies worldwide with great results. On the other hand, workplace safety constitutes a key issue for company managers due to their responsibility. The aim of this paper is to demonstrate how by the use of Six Sigma accidents can be reduce. A case study is conducted on a large European metallic packaging manufacturing company. As a result, the company got a reduction of LTA (Lost Time Accident) from 97 to 30 that saved a lot of time and cost. The sigma value achieved was 4.24. This project shows the effectiveness of Six Sigma as an improvement tool in the human resources area, despite most of the previous Six Sigma research is focused on manufacturing aspects. The case studied can be useful either for large companies and small and medium-sized interested in improving safety.

Keywords: Six Sigma; case study; workplace safety; DMAIC; process improvement

1. Introduction

According to the International Labour Organization [1] *"more than 2.78 million deaths occur annually worldwide as a result of occupational accidents or work-related diseases. Additionally, there are some 374 million non-fatal work-related injuries each year, resulting in more than 4 days of absences from work. The human cost of this daily adversity is vast and the economic burden of poor occupational safety and health practices is estimated at 3.94% of global Gross Domestic Product (GDP) each year"*. At the European level, in the 28 member states of the EU, over 3.2 million workplace accidents which lead to, at least, 4-day work leaves and 3,876 deaths were recorded in 2015, an increase of 102 deaths compared with the year before [2]. Therefore, workplace safety is a key factor for all companies. It is a duty and moral responsibility of the company to look after the employee's protection. But, are we doing enough related to prevention? Are we alert enough? Maybe not according to previous data.

While it is true that in most countries, companies must have risk coverage insurance for labour accidents, it lacks a more proactive emphasis placed on occupational safety prevention. The problem is that many times, company safety is seen as a cost rather than an investment [3]. However, costs derived from accidents (costs of temporary disability, the value of lost time and production, legal costs, etc.) may have more impact on results and the company image than those in terms of prevention and training [4,5].

Therefore, it is an important and challenging issue for companies and governments to effectively prevent and reduce occupational injuries [5,6]. Particularly, at the organisational level, this task should concern not only to the human resources (HR) management department but to the whole organisation [5,7].

There are some methodologies for improving company processes that could be used for this purpose such as Lean, Six Sigma or TQM [8]. Specifically, Six Sigma was chosen because it has been used in different contexts for quality improvement including those related to the company's human resources safety [9–14]. According to Ray et al. [11], this systematic and logical approach could identify many root causes for accident identification and deployment of corrective actions to relevant processes. In this sense, the U.S. Department of Energy’s nuclear weapons program effectively implemented Six Sigma in Los Alamos National Laboratory Plutonium Facility allowing to minimise lacerations in a Radiological Control Area and ergonomic injuries [9]. It was also used to improve safety and accident prevention in a coal mine [10] or in the solid waste collection process in developing countries where exists a high number of workplace accidents [12]. In these cases, Six Sigma was used to rank and identify the influence factors and potential hazards for reducing occupational accidents and ensure safety.

This article describes the real implementation of Six Sigma in several manufacturing locations across Europe of a large European aerosol and food metallic packaging manufacturing company in order to exemplify its usefulness for reducing the number of accidents and its associated cost.

This study explores how to improve occupational safety minimising hazards and unsafe conditions in the company production area performed in standard (assembly, press department and lithography), non-standard (diagnostic, inspection, remove jams and set-ups) and preventive maintenance operations. The step-process (DMAIC) detailed in this case study can be followed by other companies in similar situations, regardless of their size and resources.

2. Theoretical framework

2.1 Six Sigma Philosophy

Six Sigma is a business process improvement strategy, based on the principle of measuring, monitoring and controlling processes, that provide an organisational structure for continuous improvement [15]. It is also a logical and methodical approach to achieving continuous improvements in areas critical to the success of any manufacturing or service-oriented business [14]. Its main objective is to achieve business goals and improve company performance through controlling defects and reducing variation in processes [8]. Six Sigma means that the company offers only 3.4 defects per million opportunities (DPMO), which means a high quality that reaches 99.99966%.

Its success in the industry began in the late 80s when Motorola got the Malcolm Baldrige National Quality Award for its improved competitiveness through this quality strategy [16]. Moreover, it has been a popular topic among researchers and practitioners and has resulted in an extensive literature emerging since 1990 [17]. These studies are mostly based on the case study methodology [18], describing implementations in real-life contexts to test its applicability and to provide empirical evidence of its benefits. For example, it has been in the construction sector for improving productivity and to reduce project delays [19], in some manufacturing industries for increase quality and therefore business performance [20,21], and even in services like logistics [22] or banking [23]. Moreover, there are multiples cases applied to healthcare where it has been used to successfully reduce patients' length of hospital stay [24], to guarantee the correct administration of medications [25], to improve the management of samples to avoid extra costs-errors [26], among others [27].

Despite many successful implementations, some projects fail for several reasons as the lack of resources or management involvement [28]. It should be said that compared with other approaches as Lean, Six Sigma techniques require more statistical complexity [29]. This fact is a barrier for smaller companies [30].

2.2 Occupational safety

Heinrich [31] was the pioneering occupational safety researcher who identified causal factors of industrial accidents including "unsafe acts of people" and "unsafe mechanical or physical conditions". He was considered the first creator of an accident model based on the domino model of accident causation in which an accident is a sequence of five factors: the working environment, the human being, the hazard, the accident, and the injury. Several years later, Bird [32] developed the Heinrich theory based on the analysis of 1.7 million accident reports showing the relationship between the type of accidents exhibited in Figure 1 [33]. At the triangle's base appears the so-called unsafe conditions and acts, that is, things in poor conditions or situations such as slippery floors, low light, dirty or broken spaces, and equipment, etc. In these conditions near misses can occur. Depending on whether this situation continues in the same state or deteriorates, these almost accidents can become serious accidents, or even lead to death. For every 600 incidents, although the proportions may vary, there could be 30 minor accidents, 10 serious accidents that would result in some working days lost, and 1 fatal accident that could result in death or permanent disability of a worker.

INSERT FIGURE 1

Hosseinian et al. [34] conducted a review of accident causation models for providing explanations of why accidents happen. The most important theories in this regard were mainly focused on people, management aspects, and physical characteristics of hazards. Among them, the accident triangle (Heinrich and Bird's Pyramid) is one of the most relevant and it has inspired a lot of research trying to explain the relationship between minor accidents and a fatality [35–38].

Although some authors argue that theory is too simplistic [39] and should be amplified including behaviour-based safety [40] or revising the safety pyramid ratios [38], the validity of its assumptions is still valid. Marshall [41] states that the occurrence of minor accidents is a useful signal for assessing and forecasting the overall safety performance of a firm. Besides, Bellamy [42] pointed out that the accident triangle provides a useful indicator of lethality when separated into different hazards. The underlying causes of the more minor and frequent incidents could help prevent the bigger accidents of the same hazard type.

Therefore, before a fatal accident, there are previous alerts that companies must tackle.

3. Methods

3.1. Case study methodology

We use the case study methodology developed by Yin [43] to describe the Six Sigma deployment that took place in a large aerosol and food metallic packaging manufacturing company from Germany to reduce occupational accidents. A case study based-methodology is empirical research that studies a phenomenon within its real context, especially when there are more variables of interest than observational data and, as a result, is based on multiple sources of evidence. In Six Sigma literature, as we aforementioned, most of the research is conducted using this methodology as each project has its particularities.

During the project design and its implementation, multiple people were involved starting from the project team and the top management. They were the facilitators of the information. In the developing of the study, we gather the information from them and detail the implementation of the Six Sigma project through DMAIC.

3.2. DMAIC

General Electric (GE) played a very important role in the development of Six Sigma as a methodology because they added the "define" step at the beginning of the MAIC process (measure, analysis, improve and control) to clarify the problem addressed [44].

It was in 1995 when the implementation of Six Sigma in General Electric's began in the U.S. and, a year before in the European sites and global operations. CEO Jack Welch was the driving force behind this implementation, leading the rest of the company to rally behind. This fundamental change in operations philosophy and methodology began when Welch became aware of GE's many setbacks and, the company often falling short of its potential. Working with employees and consultants, Welch found many improvement opportunities that had been previously ignored. This build-up of waste and defects was holding the company back, losing them money, and slowing down their production and holding back financial profits.

DMAIC is especially useful when the cause of the problem is not clear [45] because its five steps are a systematic approach in the search for the best solution.

On the other hand, multiple tools and techniques can be used in each step and represent a vital role in the success of the implementation process. The main tools used in the case studied are summarised in Table 1.

Table 1. Summary of DMAIC

STEP	TOOLS USED	KEY LEARNINGS
D	Business decision tree, SIPOC	Understand links between Environmental Health Safety and global business strategy

M	LTA OSHA[1] index, AR&R	Measurement system analysis impact Repeatability and reproducibility measurement
A	Benchmarking, CTQs, Fishbone diagram, Pareto diagram	Benchmarking allows identifying opportunities Identification of the main causes of accidents
I	Relationship between variables Brainstorming and multi-voting method	Understand relevant X's to reduce LTA (hidden factory factors)
C	Process control	Importance of sustain improvement

Note: AR&R = Repeatability and reproducibility analysis ; CTQs = Critical To Quality; LTA OSHA = Lost Time Accident - Occupational Safety and Health Administration; SIPOC = Suppliers, Inputs, Process, Outputs and Customers

Source: Own elaboration

4. Case study

As previously mentioned, the study focuses on a large aerosol and food metallic packaging manufacturer company ("RK" *name anonymised*), with an annual turnover of 800 million EUR, about 1300 employees and working capital of 22 million EUR, owing 21 manufacturing sites around Europe.

After several years of getting negative results, the group was in the process of selling. At that point, the management considered that it was necessary to improve its image for getting a potential buyer. They analysed different aspects of the company that needed to improve, including among them occupational prevention and employee safety as it has been found a direct relationship between accidents and quality performance [46,47], profitability [48,49] and productivity [5,47]. Therefore, in a dirty and messy company with accidents and workers injured, productivity is usually low and products have questionable quality, what it is inconvenient if potential buyers are being sought. Therefore, safety is a parameter that should be taken into account to improve productivity and quality. Moreover, one of the possible companies interested in acquiring the group

[1] OSHA (Occupational Safety and Health Administration) is an agency of the United States Department of Labor and its mission is to "assure safe and healthy working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education and assistance". Incident rates have been standardized by OSHA and other regulatory agencies as, for example: OSHA Incident Rate, OSHA Lost Time Incident Rate, OSHA DART Rate depending of what it's taken into account (deaths, only days away from work, job transfer or restriction or other recordable cases) related to accidents or illnesses. (http://www.ecsinsure.com/wp-content/pdf/OSHA%20Incident%20Rate%20Calculations.pdf).

was from the U.S., where they have a very demanding level of safety and prevention for legal requirements and those imposed by insurance companies.

All the incidents, near misses and accidents produced during a full year, were analysed and it was observed that the LTA-OSHA Index (Lost time accident – Occupational Safety and Health Administration) was 97.13. It represents on average the days of each work leave. This value was excessively high and caused an over-cost of 378,000 EUR per year in the concept of total temporary work disability. Although insurance or mutual companies cover most of this amount, this has an impact on the insurance premium in the following years. Therefore, it represented a real problem and the management decided to intervene.

RK planned to create a common internal safety management system (Environmental Health Safety (EHS)) for all manufacturing sites. It would respect all country's laws and allow them to be understood among all of them, due to the different regulations and different ways to interpret safety reports and indexes of each country. For achieving success, it was of vital importance that managing teams understood that occupational safety and prevention affected directly or indirectly their profit loss account. To do so, the president of RK decided to conduct a pilot test in one of their plants to verify and exemplify the impact that an improvement in safety has on productivity.

The president commissioned the project to the general director of the plant located in Spain who was an expert in safety management since he previously worked at General Electric and had already led a Six Sigma implementation. He created a working group with three managers of two other plants (the UK and France) for facilitating the knowledge transfer of the Six Sigma project to those plants creating an EHS framework). It should be highlighted that approximately 85% of the group operators worked in these three plants (about 650 workers).

The decision to carry out the implementation in Spain was twofold. On the one hand, they were adaptable and used to changes, and on the other, data was available and reliable. The recent changes made in that plant obligated to register all the information systematically and therefore, all data was already checked. Subsequently, the initiative would be implemented in all the European plants when its applicability was demonstrated because it was a common problem throughout Europe.

Any hazard or unsafe condition is a potential accident in the business process. The problem is that no company can operate without hazards, it is almost impossible. Achieving Zero accidents was an ideal target. So, the project scope was especially to reduce hazards and unsafe conditions in production areas of the company performed in standard (assembly, press department, and lithography), non-standard (diagnostic, inspection, remove jams and set-ups) and preventive maintenance operations. It would lead to a Lower Severity Rate, reducing the number of lost time accidents (LTA) in the company, equivalent to the time lost in each temporary disability.

5. Implementation of Six Sigma DMAIC methodology in the Spanish plant

5.1. Define

The main objective of the implementation of Six Sigma must be well described in the "define" phase, as well as the critical project to be developed, the "defect" that the company should eliminate, and the expected economic impact. All this information is summarised in the project charter (Table 2).

Table 2. Project charter

Detailed project background	Goal statement	Project scope
Significant cost per LTAs: 378,000€ and 97.13 days per LTA	224,000€ savings per year	The project is scoped for workers' safety
Project Metric /CTQ	**Project Team**	**Project timeline**
y: Yield- Loss Workday Index Defect = Lost time accident (LTA) that represents high costs	Black belt (J.B.) Master black belt (R.S.) Sponsors (R.F. y F.V.) Project team: multidisciplinary Spain, France and the UK total of 9 people (Operations, Human Resources, Finance): 1 people per function per country	6 months

Note: CTQs = Critical To Quality; LTA = Lost Time Accident

Source: Own elaboration

The composition of the project team met the Six Sigma standards involving different function managers, including HR, Operations and Finance, a facilitator (Six Sigma Black Belt), a master black belt (HR Director) and two sponsors who were managers of the Spanish plant. Workers were a critical stakeholder and their participation was secured through their representation or feedback communication.

RK had incurred large costs for employees' temporary disability in recent years. So, the main objective of implementing Six Sigma was to reduce the high impact of LTA (considered as a defect in the project) in business and legal liability and, on the other reducing the cost of each LTA recordable[2] in OSHA. It was planned to achieve savings of more than 224,000 EUR per year (form 28,000 EUR to 7,000 for each LTA).

In this definition phase, therefore, the variables that the company wanted to improve to achieve the objective were identified. These are commonly identified as "Y" and "y" (variables for improving) and "x" (factors that affect "y" and must be modified) [50]. Specifically:

- Y is the main variable for monitoring, that is, on which it is wanted to act. In our case, it was the LTA cost, which at that time was 378,000 EUR.
- y is the unit to improve to get the Y to improve. The LTA-OSHA index of 97.13 was calculated (this value in previous years had exceeded 180), approximately 97 days lost because of accidents that involved high costs. LTA was considered as the defect to be improved. This data was provided by the HR Department.
- X were all factors affecting the current safety system and that influence the objective pursued. X were factors included in prevention through the Safety Management System (based on continuous risk assessment system available on "floor" and in Safety representative's promotion (safety contacts).

The SIPOC diagram included in Figure 2, visually details de company processes and the histogram embedded identify which process produced the highest LTA (Lost Time Accident) value and its evolution. As can be seen, the assembly department had the greatest number the last to years (can-body soldering and top and bottom seaming process).

INSERT FIGURE 2

Finally, Six Sigma ultimate goal is always the maximisation of the company's profit and the value of the shareholder. In this case, this is done through improving safety as shown in Figure 3.

INSERT FIGURE 3

[2] *"Recordable incidents are incidents that resulted from an exposure or event in the workplace and that required some type of medical treatment or first-aid"* (https://www.rit.edu/academicaffairs/outreach/OSHA/documents/Module5/M5_IncidentRates.pdf).

The shaded part of Figure 3 corresponds to the internal part of the prevention plan where RK could act for achieving the objective. An internal risk assessment was carried out, as well as another external one. A joint analysis (made by the company itself and the mutual technician) was done to certainty know in what conditions the company was in terms of occupational safety. A safety audit can detect that a machine is wrong, facilities work poorly, but problems related to moral and personal issues are more difficult to detect. On the other side, these unsafe conditions of personal nature generate variability in the processes, accidents, and problems of workers' concentration. It was not only about complying with legal requirements but also complying with moral or ethical aspects.

5.2. Measure

The unit of measure used "y" was Lost time per accident (LTA) OSHA index, so, the first step was to measure the lost period per temporal disability. *OSHA* "*has established specific mathematic calculations that enable any company to report their recordable incident rates, lost time rates and severity rates, so that they are comparable across any industry or group"* [51]. In OSHA, the standard base rate for the calculations is based on a rate of 200,000 labour hours. This number (200,000) equates to 100 employees, who work 40 hours per week, and who work 50 weeks per year. In our case, RK used 1,720 hours per worker and year as they were set by a labour agreement, for this reason, the multiplicator is 172,000.

The total year working days per hour was 304,588h.

LTA-Osha Index = (172 days/304,588h) x (1,720h x 100) = 97.13 days

The use of OSHA standards served to facilitate later repeatability and reproducibility. Ensuring repeatability implies confirming that if the research was repeated, there would be very little variability in the calculations in the measuring system, while reproducibility refers to the variability that could occur due to the change of operator. This is called AR&R (*Repeatability and reproducibility analysis*) [16].

5.3. Analyse

If the measurement system is correct, the third phase of DMAIC, the analysis phase, is proceeded. An analysis of the evolution of the LTA-OSHA Index of prior periods was carried out. It was observed that three years ago the index got a value of 184, i.e. on average, each LTA lasted more than 6 months (Figure 4).

INSERT FIGURE 4

The objective was to move from an LTA-OSHA index of 97.13 to a maximum standard significantly lower. It was set at 30 for the next two years after the implementation of Six Sigma, first for the Spanish plant and then for all factories.

A benchmarking was carried out with the data from the group manufacturing sites (Figure 5). The Spanish plant was the 14^{th}.

It should be noted that some plants often did not report information on temporal disabilities. They did it only when they felt obligated or because an accident had occurred and it was really necessary. For this reason, some plants have zero values. There was no common safety policy for the entire company. This figure is representative of the relative importance that incident and accident prevention had for many of the plants (numbers are used in Figure 5 to keep anonymous the site's name).

INSERT FIGURE 5

In the analysis phase, RK should identify the sources of the safety variability (X's), i.e. the sub-processes of the company that affected the objective of the project. To analyse the relationship between the dependent variable (LTA) and the independent variable (accidents) and its main causes, a CTQ map was performed to identify why the accidents had occurred (Figure 6).

INSERT FIGURE 6

In total there had been 56 accidents that year due to different causes: lack of method, unsafe practice, unsafe condition and lack of experience. The specific causes that produced more accidents are shaded (Figure 6). Not using PPE was what caused more accidents (22) followed by communication missing (16). Therefore, it is necessary to raise awareness of the importance of PPE, it is not merely a normative issue. Despite what one might think at first, there was no accident due to turnover or dirtiness.

This analysis shows that most of the above accidents (specifically 83,14%) could be attributable to worker's behaviour (e.g. unsafe practices such as not following the method or do not use PPE) (Figure. 7). And, to a lesser extent (16,07%), they could be management related (machinery, tools and environmental).

INSERT FIGURE 7

As previous research on Six Sigma, the Fishbone diagram was used for analysing this complex problem to identify sources of variation [12,52]. The defect is shown as the fish's head, facing to the right (LTA in our case), with the causes extending to the left as fishbone (environment, communication, method, machine, people, etc.). With sub-branches for each root-causes, sources of variation are identified (Figure 8).

Next, we detail the three root-causes that produce more accidents.

INSERT FIGURE 8

Regarding communication (16 accidents) two potential causes affecting LTA were identified. On the one hand, communication within the company (in all directions) and, on the other, the lack of labelling. On each machine, all risks arising from its use should be identified with an adhesive.

Similarly, causes related to machine such as missing protections, since operators often remove protection for carrying out the task more comfortably; safety switches deactivated because workers can continue working while the maintenance personnel does not arrive or missing covers that leave exposed gears and this is a danger they may accidentally put a hand.

Finally, people related causes like the ones aforementioned: people do not use PPE; they usually perform their work unsafely for having to perform tasks in a short time or for not being aware of their risks. Moreover, when workers carry out the same process many times, they cease to be aware of the risk and assumes that everything is under their control (without checks) until an accident occurs. Another risk is to assign tasks to people who are not prepared or trained to do it.

In the end, company managers should make decisions as they are legally responsible. They must supervise in situ and frequently what is happening in the plant if they remain in their office, they only get the information from third parties. Especially in Safety Management, responsibility for people and process safety cannot be delegated. According to EU guidelines and country-regulations is mandatory to have a well-trained risk prevention technician operating in a well-defined prevention system. With this, you are complying the legislation but it is not enough, you must be duly informed at all times of what is happening in the plant.

5.4. Improve

In the improve phase, the company had to set the improvement objectives and establish a new method of operation and solutions concerning some factors that affect LTA. In this sense, the company set 30 the LTA-OSHA index for achieving the objective of 224,000€ of savings.

A common method of safety was established based on the relationships identified, and some decisions were made for involving all the organisation in the same purpose. It was found that safety was a problem related to people, methods, and processes, therefore, the company decided to implement actions focused on them. These actions reached the consensus by the multi-voting method after several brainstorming sessions between the project team and the top management.

They were related to operational discipline, organisation and standardisation (Figure 9) because it had been found that the main problem came from workers, operational discipline was the most relevant aspect where safety representative paid attention to.

INSERT FIGURE 9

The actions with greater impact and most follow-ups by managers were:

- One safety representative per department.
- Safety committee meetings every month and unforeseen visits.
- Two safety contacts per month and area.

Involving all levels of the organization to make them aware of the problem was the key because coercive disciplinary measures were not effective. Therefore, less people-dependent management and control processes were created and they established processes were several people shared the responsibility and it was seen that the errors were reduced.

Moreover, regular risk assessment and training, communication improvement, regular (daily) audits, safety improvement plan, and machine maintenance, etc. actions were carried out.

Low impact actions conducted were: set safety awards, integrate safety in ISO and standardisation (basically drafting a guide or rules of procedures).

All these actions were communicated to all the personnel involved to understand that it was necessary to establish a clear policy and protocol regarding the safety plan. To improve the operation of the plant due to safety improvement there must be a genuine commitment to safety (not just the legal ones).

After the implementation of the aforementioned actions, unsafe conditions improved and this had a positive impact on the plant results.

5.5. Control

In the last step DMAIC (control phase), the validation methodology for measuring results was followed. It was necessary to ensure that RK could improve the LTA-OSHA index. The company acquired the routine of carrying out periodical meetings and sharing and communicating experiences related to safety.

After several months, RK reduced the number of days per temporary disability, as the LTA-OSHA index went from 97.13 to 45.4 the first year, and to 6.2 the second. The number of accidents was also reduced, diminishing the cost per LTA from 28,000€ to 12,000€ the first year after implementation, and 7,500€ the second. The savings were 49,000€ in the year of implementation and 230,000€ the following year. Therefore, the objective was achieved. Finally, the total cost per LTA went from 378,000€ to 329,000€ and 148,000€, respectively, the next two years after implementation.

Table 3 outlines the procedures that were applied to control improvements made.

Table 3. Measurement and control system on X's in the actual application

Discipline (and Training)	Number of safety contacts per month Number of safety audits per week Number of non-conformities (auditees) New employee Induction to EHS Policy & Procedures Training in Flammable solvents handling Emergency Response training Risk Assessment communicated
Communication	EHS Policy translated & communicated Risk Assessment updated and communicated EHS Basic rules in Place, written & communicated Incident and accident reporting system formalised Lock-out Tack-out procedures formalised
Standardisation	Contractor safety procedures formalised Flammable solvents procedure formalised Work permits procedure formalised Emergency response procedure

Note: EHS = Environmental Health Safety

In this sense, it is necessary to control where the training will be reinforced, what standards and information should be communicated, and what issues will be subject to standardisation. For example, regarding standardisation, in many large companies, contractors perform different types of works and this is a common source of accidents [53]. Contractors are not usually aware of the company's norms as they are temporary. Moreover, Picchio and van Ours [54] found that temporary workers are more likely to experience severe injuries once a workplace accident took place. Therefore, the company has to take measures for protecting the whole process, independently on the internal or external character of the worker. Every external person must know and follow the company's rules. To do this, all procedures must be formalised and standardised.

On the other hand, the company established a protocol for process control, such as a workplace safety audit process (Figure 10). Managers of each area are responsible for safety auditing and recording data according to a previously specified frequency and method. If they feel satisfied with the existing conditions, then they report that everything is correct (OK). If they are not, they have to observe if the deviation from standards is due to a behavioural problem or a communication problem. In any case, it must be registered.

If the wrong conditions are due to behavioural or human factors then, this situation has to be openly discussed (safety contact). In case of communication issues, clear expectations and instructions along with formal training are required. In other cases (Not OK) it should be verified that everything has been done correctly, i.e. the methods. After that, it is also necessary to question whether the method being applied is working, is the machinery correctly used, etc. Subsequently, the safety committee should discuss the issue and make decisions (for example, changing a machine, changing the way of working).

Lost Time Accidents and first aids with time lost must be reported and investigated to establish their causes and corrective actions, this is a key requirement in all countries. However, if the real objective is to perform every work safety in a risk-controlled environment, it is of vital importance to analyse also the near misses since they are accident precursors [33]. All incidents and accidents were reported in one system (incident and accident reporting system). Thus, the risk assessment was constantly updated.

INSERT FIGURE 10

6. Conclusions and Lessons Learned

RK had a delicate economic situation as it was immersed in a sale process when they decide to carry out a Six Sigma implementation in order to improve company safety and thus, improve its image and performance for getting a better buyer.

Our results confirm conclusions of previous research such as Clarke and Taylor [6] that found on leadership interventions the key to reducing workplace accidents. After the implementation, just a very few accidents occurred at the Spanish plant. Specifically, some incidents happened but they were minor. Accident levels dropped more than 80%. The commitment of the management in all aspects related to safety was very necessary and so effective. Workers form their perceptions of safety priorities based on managers' attitudes regarding safety [55,56]. Likewise, the improvement in safety climate, conditions and training were also decisive [57].

There was not much resistance from workers because it was done naturally, with communication and training. Moreover, the responsibility was shared with the department supervisors. That is, supervisors had to be accountable, not only for the volume of production achieved but also for the level of safety indicators.

In Spain, temporary disability also includes common diseases, so, if these casualties were discounted, the level of temporal disability for accidents in the Spanish plant in the second year after implantation would be reduced to zero. With this remarkable improvement and the savings entailed, it was possible to obtain benefits in a deficit plant. The checked safety system was propagated to the rest of the group manufacturing sites.

Finally, when the buying company, which was a competing company of the group, made the previous visits for the acquisition, they could observe old but well-preserved machinery, clean plants and well organised, with a level of accidents much lower than that shown by the buyer itself. Safety improvement turned out to be a determinant factor that positively influenced the sale of the group.

Our study has implications for the design and implementation of Six Sigma methodology in safety. First, our findings suggest that the Six Sigma project carried out by RK for safety improvements can be useful for any other company in the same situation. Having high accident rates involve costs related to LTA and, applying DMAIC may help to reduce them. Second, we found that to build a safety philosophy which involves all organisation was crucial to achieving improvements. Safety is one of the main tasks of company management and the HR department, for health reasons and economic consequences. Third, the lesson learned by the members of the project team was that accident prevention should exceed the legal field and must be managed by conviction for moral reasons. Many managers consider investments in accident prevention as an obligation, i.e. as a cost. However, this is not the case, RK learned that managers need to be good leaders and take care of the people of the organisation to succeed.

Finally, the main contribution of this article is to prove how to use and implement a quality methodology such as Six Sigma for improving safety performance in any manufacturing or service operation. By following the DMAIC steps, the studied company could identify the source of safety incidents and lost time accidents that let the reduction of the high level of accidents and its associated cost.

From the corporate point of view, low performance in Health and Safety was unacceptable since it directly affected the image of the company and was a threat to their future. At the proposal of the group's president, Six Sigma was implemented in one of its plants to improve this aspect of management. Once safety results improved, the methods adopted were applied to the other plants following the steps already followed by the pilot plant.

This case highlights Six Sigma usefulness for improving any company aspect. One of the strengths of Six Sigma is that it analyses problems in depth to solve them in the long term and, its actions could become "transferable" to other similar cases. Companies must anticipate future accidents and there are tools to ensure it.

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Figure 1 Accident Triangle

Source: Adapted from Bird and Germain [33]

Figure 2 SIPOC Diagram

Note: EHS = Environmental Health Safety; ERP = Enterprise Resource Planning; ISO = International Organization for Standardization; JIT = Just in Time ; S.A.P = Systems Applications and Products; SIPOC = Suppliers, Inputs, Process, Outputs and Customers

Figure 3 Business Decision Tree

Note: EBITDA = Earnings Before Interest Taxes Depreciation and Amortization ; EHS = Environmental Health Safety

Figure 4 LTA-OSHA Index Evolution

Note: LTA-OSHA = Lost Time Accident - Occupational Safety and Health Administration

Figure 5 LTA-OSHA index benchmarking among plants in the year of the Six Sigma implementation

Note: LTA-OSHA = Lost Time Accident - Occupational Safety and Health Administration

Figure 6 CTQs Map

Note = CTQ = Critical to Quality; PPE: Personal Protection Equipment

Figure 7 Pareto diagram of potential causes of accidents

Figure 8 Fishbone diagram of factors affecting LTA

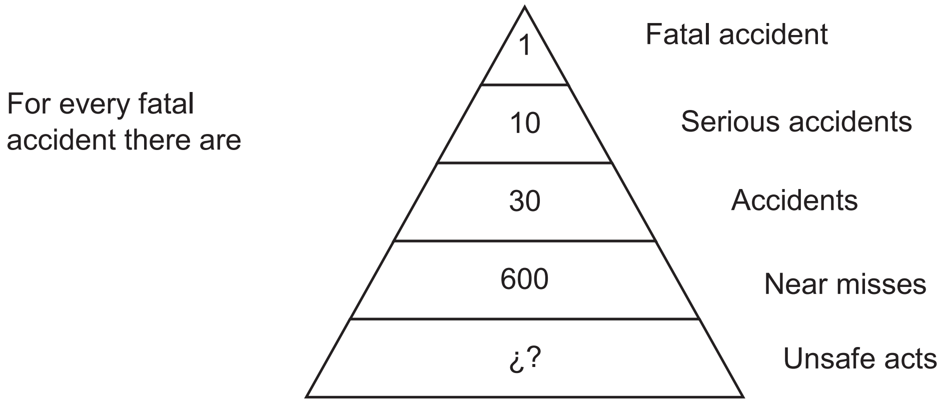
Note: LTA = Lost Time Accident; PPE = Personal Protection Equipment

Figure 9 Disciplinary actions

Note: ISO = International Organization for Standardisation

Figure 10 Implementation of process control

Figure 1. Accident triangle



Source: Adapted from Bird and Germain (1966)

Figure 2

Figure 2. SIPOC Diagram

Note: SIPOC = Suppliers, Inputs, Process, Outputs and Customers

Figure 3

Figure 3. Business decision tree

Note: EBITDA = Earnings Before Interest Taxes Depreciation and Amortization ; EHS = Environmental Health Safety

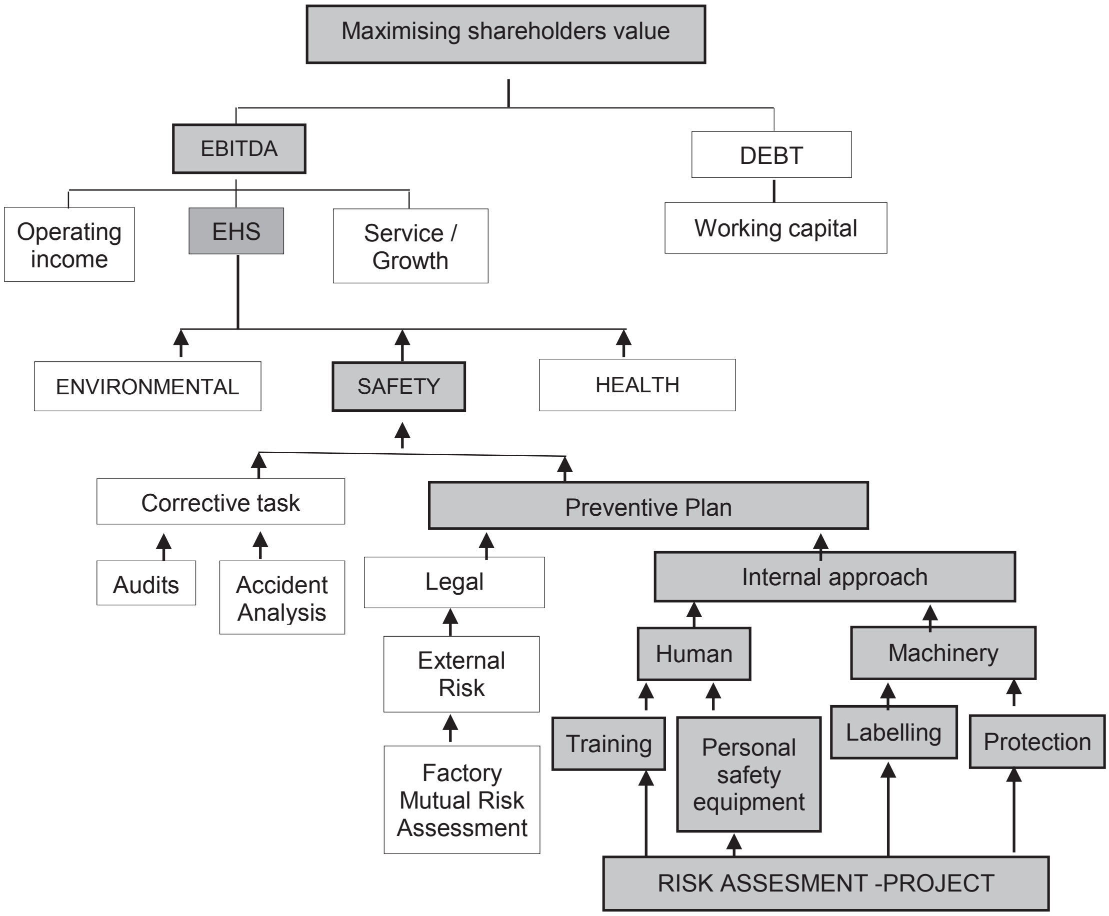


Figure 4. LTA-OSHA Index Evolution

Note: LTA-OSHA = Lost Time Accident - Occupational Safety and Health Administration

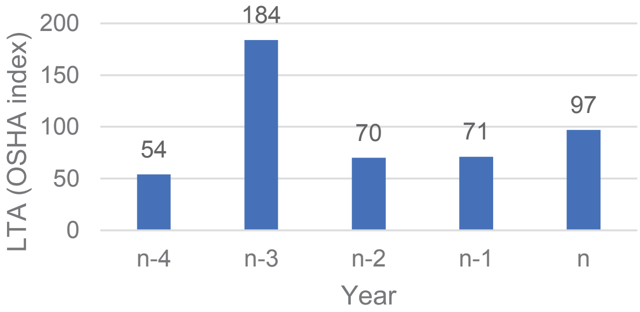


Figure 5

Figure 5. LTA-OSHA index benchmarking among plants in the year of the Six Sigma implementation

Note: LTA-OSHA = Lost Time Accident - Occupational Safety and Health Administration

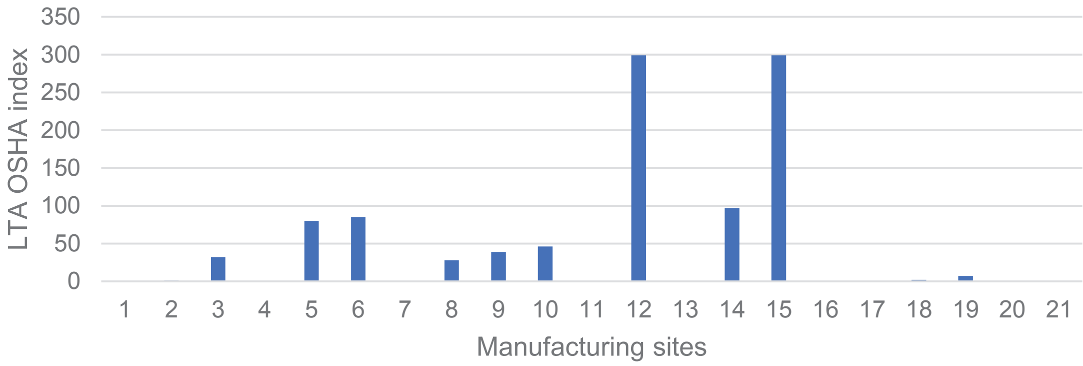


Figure 6. CTQs Map

Note = CTQ = Critical to Quality; PPE: Personal Protection Equipment

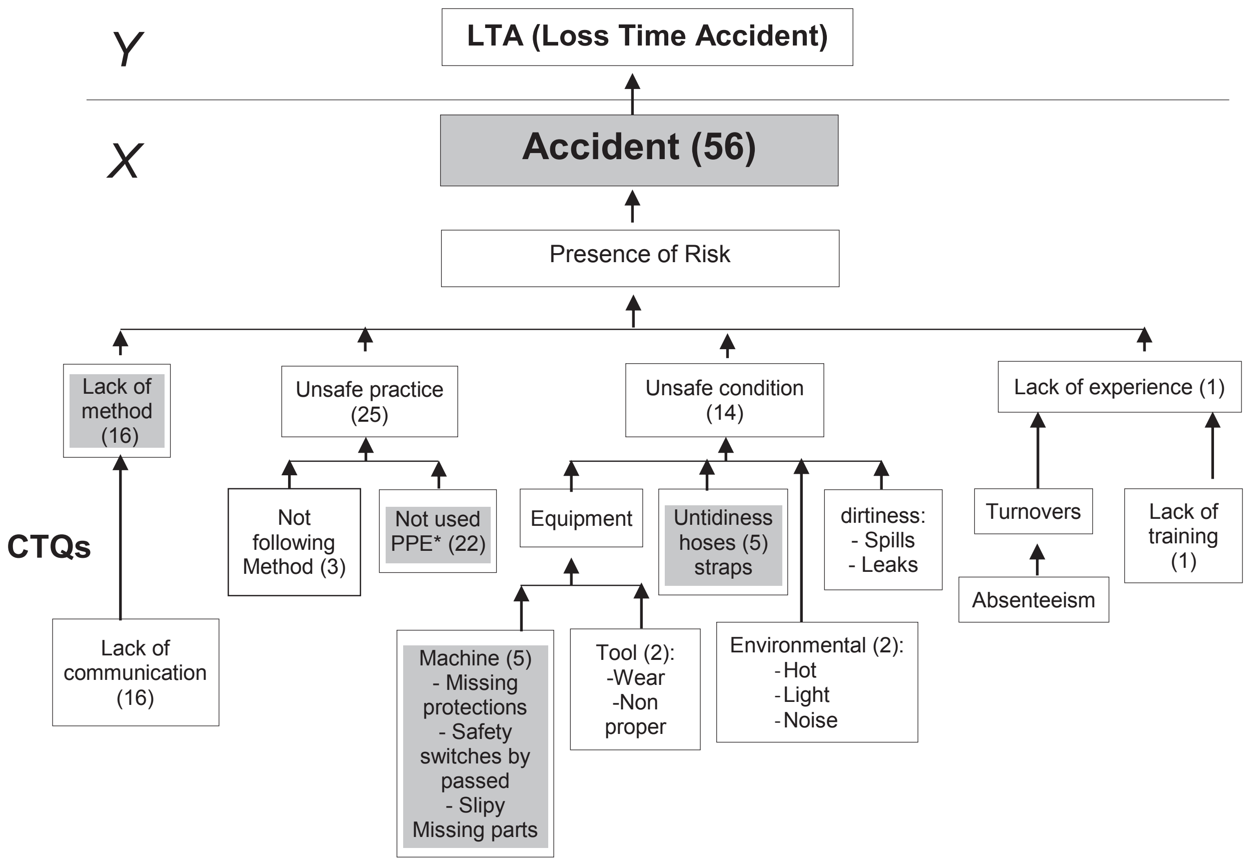


Figure 7

Figure 7. Pareto diagram of potential causes of accidents

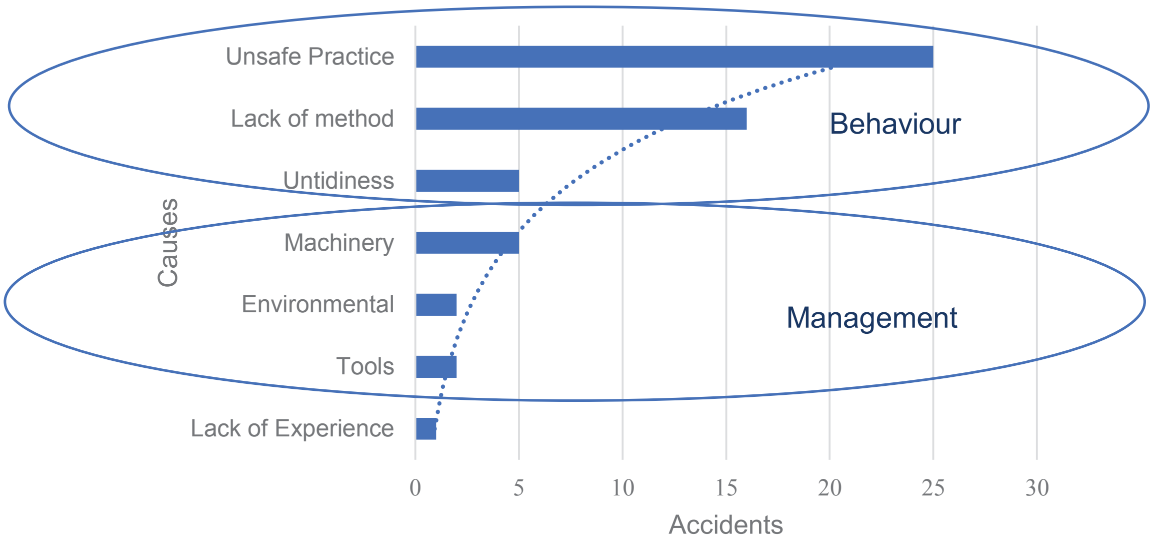


Figure 8

Figure 8. Fishbone diagram of factors affecting LTA

Note: LTA = Lost Time Accident

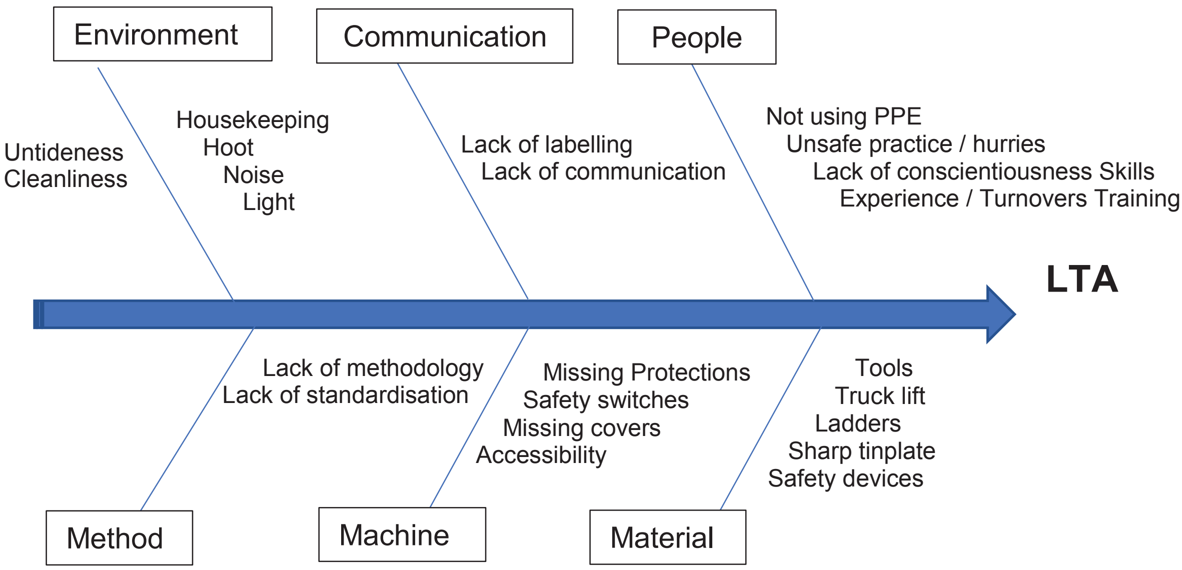


Figure 9. Disciplinary actions

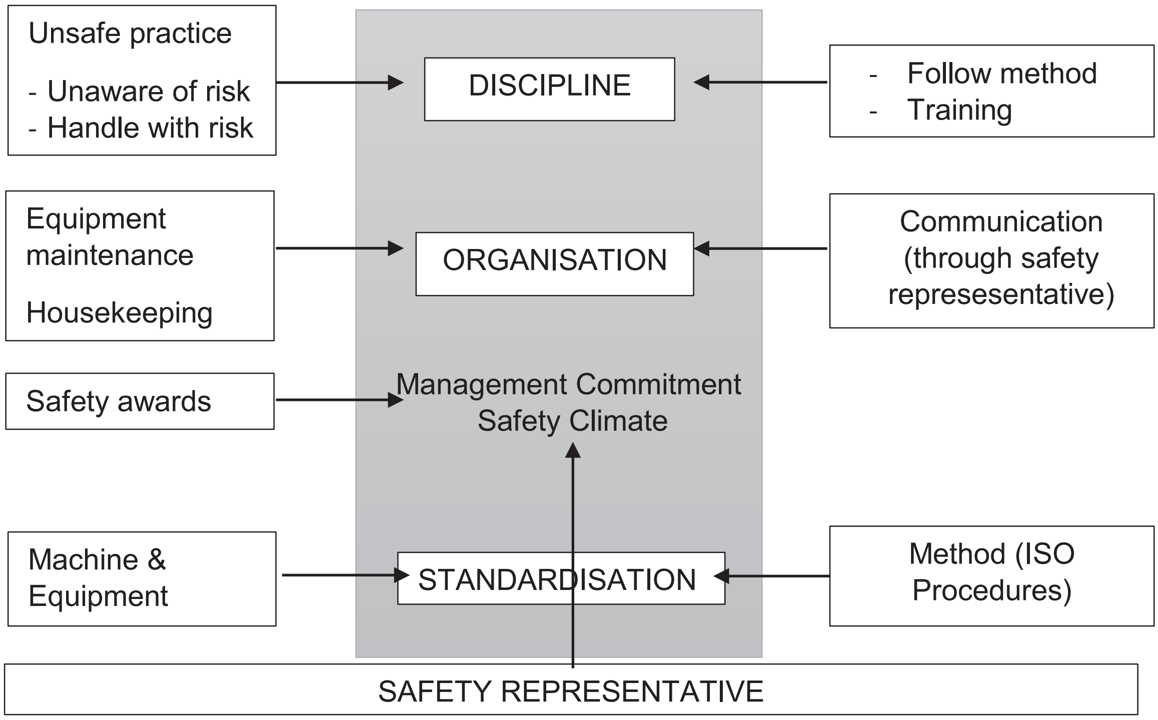


Figure 10. Implementation of process control