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Deployment of Lean Six Sigma DMAIC methodology to improve productivity of a can manufacturing industry

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Abstract: This study proposes and follows a specific and systematic Define-Measure-Analyze-Improve-Control (DMAIC)-based Lean Six Sigma (LSS) implementation framework for improving the productivity of a can manufacturing industry. A case study research methodology is adopted and implemented through the proposed LSS framework. The effectiveness of the LSS framework is evaluated in a metal fabrication industry producing metallic cans. It is found that the implementation of the LSS project improves the annual productivity of the company by about 511,992 non-defective products which can successfully lead to an increase in the annual sales of about $25,600. This improvement is expected to maintain an efficient production process, increase customer satisfaction, and enhance company's goodwill and profit. This study is expected to help improving the understanding of how LSS methodology can be implemented in solving quality related problems and offer valuable insights for practitioners in metal can manufacturing industries.

Keywords: Productivity improvement; Lean Six Sigma; DMAIC; Define-Measure-Analyze-Improve-Control; Metal can industry; Pareto chart; Control chart; Cause and effect diagram; 5-why analysis; Simulation.

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1. Introduction

The uncertain, dynamic, competitive, and globalized market environment makes the need for the manufacturers to design and develop high-quality products with lower cost a top priority. Global businesses are challenged by rapid changes of customer demand, which need to respond as quickly as possible. To deal with such challenges, organizations need to build a continuous process improvement culture in which everyone within the organization is supposed to seek for perfection. Thus, quality control has become a fundamental player in any organization for producing products and offering services with high quality standards in order to meet customers' expectation. Moreover, quality control and improvement methodologies help organizations to minimize waste and increase productivity.

A metal fabrication industry uses metals to produce a variety of products ranging from large ships, bridges or automobile bodies to small tin cans, spring, screw, nut or bolt. It is almost impossible to avoid production of substantial amount of non-conforming parts (scrap/defective and/or rework) in most of the metalworking scenarios, especially in mass production. In general, if the scrap and/or rework reduces, then the productivity (number of conforming/non-defective parts per unit time) increases and as a result, cost decreases (Shamsuzzaman and Wu, 2012). This study focuses on a metal can manufacturing industry that produces a variety of products including easy-open end (EOE) tuna can and twist off cap. The production processes of these products are facing several problems that deviate the quality characteristics of the products from the target specifications and as a result, lead to scrap and rework. Consequently, the company suffers from low productivity and difficulties in on-time delivery and satisfying customers' demand. The manufacturing system of the case industry is an automated manufacturing system involving machines, transport network (e.g., conveyors) and operators. The operators are only involved with machine setup, loading raw materials, unloading final products, and maintenance works. Several activities are followed in manufacturing a can product, and the causes of the low productivity are apparently unknown and difficult to identify them instantly.

Lean Six Sigma (LSS) is a business process improvement philosophy widely used to improve the efficiency of manufacturing processes and enhance customer satisfaction (Drohomeretski *et al*., 2014; Alblooshi *et al*. 2020). This study, therefore, adopts a LSS framework with the objective to increase the productivity of a can manufacturing industry so that customers' expectations can be fulfilled. The contributions of the study are summarized as follows: (i) developing a specific and systematic DMAIC-based LSS implementation framework based on a comprehensive literature review, author's industry experience, and input from the case industry, (ii) implementing the proposed framework in the case industry to identify the problem areas that mainly cause the low productivity, (iii) proposing different solution-approaches to improve the productivity of the case industry, (iv) validating the proposed solution-approaches using discrete-event simulation model, and (v) generalizing the proposed framework and lessons learned in similar organizations is expected to be beneficial.

This article is presented as follows: Section 2 provides a comprehensive literature review related to different process improvement philosophies such as Lean, SS and LSS, and their applications in manufacturing organizations. Section 3 discusses the research methodology and the proposed LSS implementation framework. Section 4 provides a brief background of the case industry, and discusses the results obtained from the implementation of the LSS framework. The lessons learned from this study are discussed in Section 5, while Section 6 concludes the study focuses and suggests future research directions.

2. Literature review

Lean, Six Sigma (SS) and LSS are widely used to improve and promote business and operational excellence. Lean principles, originated in Toyota Production System (TPS) in 1990s, have been widely used by manufacturing organizations for systematic elimination of waste and non-value-added (NVA) activities (Carvalho et al., 2011; Karim and Arif-uz-Zaman, 2013; Choomlucksana et al., 2015; Pérez-Pucheta, 2019; Murali and Prabukarthi, 2020). Lean principles target to minimize all forms of waste including high work-in-process (WIP) inventory, high defective rate, long cycle time, long machine downtime, human inefficiencies and so on. The main goal of lean manufacturing is to set up a strategy in an organization, which helps in producing high quality products according to market demand with no or little waste (Womack and Jones, 1996; Shah and Ward, 2003). The aim of lean strategy is to improve the operational efficiency by eliminating waste and NVA activities across the organization

(Marodin *et al*. 2018). On the other hand, the aim of SS, as launched by Motorola in 1987, are to improve organization's effectiveness by reducing process variation and eliminating defects (Gijo *et al*., 2011; Yousaf *et al*., 2013; Jirasukprasert *et al*., 2014; Drohomeretski *et al*., 2014; Zhang *et al*. 2015; Srinivasan *et al*., 2016; Maged *et al*., 2019). The process variability is a serious issue, which ultimately leads to wastes, low productivity, and poor-quality products (Shamsuzzaman *et al*., 2019). Six Sigma (SS) uses statistical tools extensively through a five-step DMAIC methodology to minimize variability so that the defective products resulted from a process are minimized to 3.4 part per million (PPM) opportunities (Albliwi *et al*., 2015). On the other hand, LSS is a synergy between Lean and SS that seeks to accelerate operational processes and improve process efficiency so that customer stratification and profitability can be ultimately enhanced (Drohomeretski *et al*., 2014; Alblooshi *et al*. 2020). The integrated LSS methodology uses both the Lean and SS tools to reduce waste and process variation, while contributing to improve business processes (Bendell, 2006; Laureani and Antony, 2013; Shamsuzzaman *et al*., 2018). The LSS improvement philosophy is usually implemented through the standard DMAIC methodology (Lee and Wei, 2010; Vinodh et al., 2011; Wang and Chen, 2012; Anderson and Kovach, 2014; Swarnakar and Vinodh, 2016; Ruben *et al*., 2017; Pereira *et al*. 2019; Khan *et al*., 2020). The DMAIC methodology is a five-step systematic problem-solving approach that assures a correct and effective process execution by providing a structured method for solving quality problems. The aim of this method is therefore to improve productivity and profitability through enhancing workplace safety and avoiding process inconsistencies (Soundararajan and Reddy, 2020). A brief review of some recent works on the applications of Lean, SS and LSS methodologies in manufacturing sectors is highlighted in Table 1. From Table 1, it is obvious that a variety of manufacturing organizations used Lean, SS or LSS methodologies to enhance the productivity. However, it is also noticed that a very few studies on the applications of LSS in metal fabrication industries can be found in the literature. On the other hand, almost all Lean projects have been implemented without following any systematic implementation methodology, whereas almost all SS or LSS projects have been implemented following the standard DMAIC methodology. However, a specific and systematic framework for implementing SS or LSS project to handle specific problems is really needed and usually more effective than the standard version (Zhang *et al*. 20,15; Garza-Reyes *et al*., 2016).

Table 1. A systematic review of Lean, SS and LSS applications in manufacturing industries

Source	Application area	DMAIC/ Lean cycle	Tools and techniques used	Brief review
Carvalho *et al*. (2011)	Metal structures production	None	5S, mistake proofing, standardized procedures, production activity control, layout reconfiguration	Lean manufacturing principles were used to improve production process by reducing lead time, WIP, delivery delays, and defects and errors in assembly and production process in a company producing several assorted products for the civil construction.
Karim and Arif-uz-Zaman (2013)	Electrical control and communication cubicle assembly	A new lean implementation framework	Process flow map, time study	A methodology for successful implementation of lean strategies was proposed to systematically assess and improve the manufacturing leanness.
Singh and Singh (2013); Jasti and Sharma (2014); Prasad and Sharma (2015)	Auto-parts manufacturing; Foundry industry	None	VSM (Value Stream Mapping), Process flow map	VSM concept was used to improve work-in-process (WIP) inventory, cycle time and production lead time of a manufacturing system.

Chiarini (2014)	Motorcycle components manufacturing	None	VSM, Cellular manufacturing, SMED (*Single-Minute Exchange of Dies*), TPM (*Total Productive Maintenance)*	Investigated the application of Lean tools in reducing the environmental impact on manufacturing companies through empirical research.
Choomlucksana *et al*. (2015)	Sheet metal stamping	None	Visual control, Poka-Yoke, 5S	Lean manufacturing principles were used to improve the productivity by reducing processing time of polishing stage, non-value-added activities, and overtime cost.
Batra *et al*. (2016)	Precision tool manufacturing	None	VSM, Kanban	Investigated the significance of VSM in the lean transformation of an automotive industry and then applied the same in a tool room.
Pérez-Pucheta (2019)	Delivery time of spare parts in an automotive plant	None	Process flow map, VSM	Focused on using Lean tools in reducing excessive delivery time of spare parts to national and international dealers of an automotive company.
Sousa *et al*. (2019)	Tire manufacturing	None	Process flow map, Pareto chart, fish-bone diagram, control chart	Focused on using Lean tools in reducing lack of strip alignment in joining breaker in tire manufacturing.
Murali and Prabukarthi (2020)	Furniture manufacturing	None	Time study, demand forecasting, Pareto chart, VSM, fish-bone diagram, simulation	Lean manufacturing principles, demand forecasting, and simulation were used to improve the productivity of a furniture manufacturing industry.
Kumar and Sosnoski (2009)	Tool manufacturing	DMAIC	Brainstorming, Pareto chart, VSM, fish-bone diagram, histogram, control chart	Dealt with finding a way of reducing the amount of warp incurred in punches during heat-treat process of a manufacturing of tooling using Six Sigma.
Gijo *et al*. (2011)	Grinding of automobile parts	DMAIC	Pareto chart, fish-bone diagram, Gemba, ANOVA (Analysis of Variance), Gauge R&R (Repeatability and Reproducibility), DOE (Design of Experiments)	Dealt with reducing defects in a fine grinding process of an automotive company using Six Sigma.
Singh and Khanduja (2011)	Piston castings	Modified DMAIC	Process flow map, Pareto chart, Cause-Effect Matrix, DOE, ANOVA	Dealt with decreasing the scrap of piston castings in a medium-sized make-to-order type foundry using Six Sigma.
Yousaf *et al*. (2013)	Pump casing manufacturing	DMAIC	Process flow map, SIPOC (Suppliers, Inputs, Process, Outputs and Customer) diagram, Pareto chart, Cause-Effect Matrix, control chart, Gauge R&R, ANOVA, regression analysis	Focused on the reduction of defective rate of a pump casing manufacturing industry using Six Sigma.
Kumaravadivel and Natarajan (2013)	Flywheel casting	DMAIC	Process flow map, SIPOC diagram, Cause-Effect matrix, FMEA (Failure Modes and Effects Analysis), RSM (Response Surface Methodology), ANOVA	Focused on reduction of defects in the castings of flywheel in a foundry shop using Six Sigma.
Jirasukprasert *et al*. (2014)	Rubber gloves manufacturing	DMAIC	Pareto chart, process flow map, fish-bone diagram, DOE, hypothesis testing, ANOVA	Investigated the impact of oven's temperature and conveyor's speed on the productivity of a rubber gloves manufacturing industry using Six Sigma.
Sharma and Rao (2014)	Crankshaft manufacturing	DMAIC	Process flow map, fish-bone diagram, FMEA, ANOVA, control chart	Focused on reducing the process variations of the stub-end-hole boring operation of manufacturing a crankshaft using Six Sigma.
Srinivasan *et al*. (2014)	Shock absorbers manufacturing	DMAIC	Pareto chart, brainstorming, fish-bone diagram, DOE and orthogonal array, ANOVA	Focused on reduction of two imperative responses namely peel off and blisters in spray painting process producing shock absorbers using Six Sigma.

Ghosh and Maiti (2014)	Engine head casting	DMAIC	Pareto chart, Process flow map, brainstorming, fish-bone diagram, cost of poor quality, regression tree, run chart	A data mining approach was applied for decreasing the rejection rate of castings of six-cylinder engine head in a foundry shop using Six Sigma.
Zhang *et al.* (2015)	Cold rolling	DMAIC	Process flow map, fish-bone diagram, FMEA, DOE, ANOVA, regression analysis	A Black Belt project was conducted to improve the cold rolling capability to meet the thickness requirements in a large cold-rolling mill using Six Sigma.
Srinivasan *et al.* (2016)	Furnace manufacturing	DMAIC	Pareto chart, SIPOC diagram, fish-bone diagram, DOE and orthogonal array, ANOVA	Conducted a study in a furnace manufacturing company to reduce the rejection of furnace nozzles due to the deviation in the diameter of the furnace nozzle hole using Six Sigma.
Lee and Wei (2010)	Printed Circuit Board (PCB) manufacturing	DMAIC	Process flow map, Cause-Effect Matrix, time value chart, FMEA, ANOVA	Mould changing time in In-circuit test process in a PCB manufacturing company was investigated and improved using LSS.
Vinodh *et al.* (2011)	Automobile valve manufacturing	DMAIC	Process flow map, Pareto chart, VSM, fish-bone diagram, 5S	Dealt with improving first time right percentage of the valve assembly line of an automobile valve manufacturing organization using LSS.
Wang and Chen (2012)	Flat panel display equipment manufacturing	DMAIC	SIPOC diagram, control chart, Pareto chart, FMEA	Focused on reducing differentiated cost rates of forecasting processes in a flat panel display equipment manufacturing company using LSS.
Timans *et al.* (2012)	Manufacturing SMEs	None	Questionnaire, Statistical analysis	An empirical study was conducted to identify critical success factors for the implementation of LSS in Dutch manufacturing/engineering small- and medium-sized enterprises (SMEs) using LSS.
Anderson and Kovach (2014)	Welding defects in turnaround projects	DMAIC	SIPOC diagram, process flow map, Pareto chart, fish-bone diagram, FMEA	Demonstrated how LSS methodology can be applied successfully in construction industry to address issues in reducing defective welds.
Swarnakar and Vinodh (2016)	Automotive components manufacturing	DMAIC	SIPOC diagram, process flow map, VSM, fish-bone diagram, Pareto chart	LSS framework was implemented in an automotive component manufacturing organization to reduce non-value-adding activities and negative effects from assembly line significantly.
Ruben *et al.* (2017)	Automotive transmission components manufacturing	DMAIC	SIPOC diagram, Pareto chart, VSM, fish-bone diagram, Kaizen, layout reconfiguration, 7S audit	Dealt with reducing overall defects and environmental impacts concurrently to improve the firm's operational and environmental performance using LSS.
Meena *et al.* (2018)	Automobile pump manufacturing	Modified DMAIC	Process flow map, Pareto chart, fish-bone diagram	Focused on reducing defects in problems related to maintenance methods and informal issues using LSS.
Pereira *et al.* (2019)	Mould manufacturing	DMAIC	VSM, Waste analysis, Pareto chart, OEE (Overall Equipment Effectiveness)	Focused on improving mould fabrication process by reducing unavailability of operator, waiting time between processes steps and tool exchange time using LSS.

Chaudhary *et al.* (2019)	Tools and die manufacturing	DMAIC	VSM, control chart, fish-bone diagram	Focused on improving heat treatment process and hardness quality in manufacturing of precision tools and die using LSS.
Khan *et al.* (2020)	Caravan manufacturing	DMAIC	Pareto chart, fish-bone diagram, simulation, control chart	Dealt with productivity improvement of a caravan manufacturing company by minimizing waste in the production of wooden doors of the caravans using LSS.

3. Research methodology and proposed LSS implementation framework

This section briefly discusses the research methodology adopted and introduces the DMAIC-based LSS framework proposed in this study.

3.1 Research methodology

This study uses a case study research methodology. Yin (2014) defines case study as an empirical inquiry that investigates a contemporary phenomenon within its real-life context. Generally, a formerly developed theory is used as a template in a case study research with which the results obtained from the case study is compared. The required data and information in this case study were collected from historical records and interviews with different personnel at different levels within the case industry. The statistical analysis and graphical presentations of the results were accomplished using Minitab statistical software at 5% significance level. In addition, ARENA simulation software was used to develop simulation models with the objective to analyze the performance of the proposed solution approaches under various conditions.

3.2 LSS implementation framework

A comprehensive literature review was conducted using relevant search keywords to identify the previous studies focus on LSS implementation in manufacturing industries, especially in metal fabrication industries. The information was also collected from Production Manager, QA Engineer, and operators of the case industry. Finally, based on the literature, input from the case industry and authors' theoretical and industrial experience, a specific and systematic LSS implementation framework was developed as shown in Figure 1.

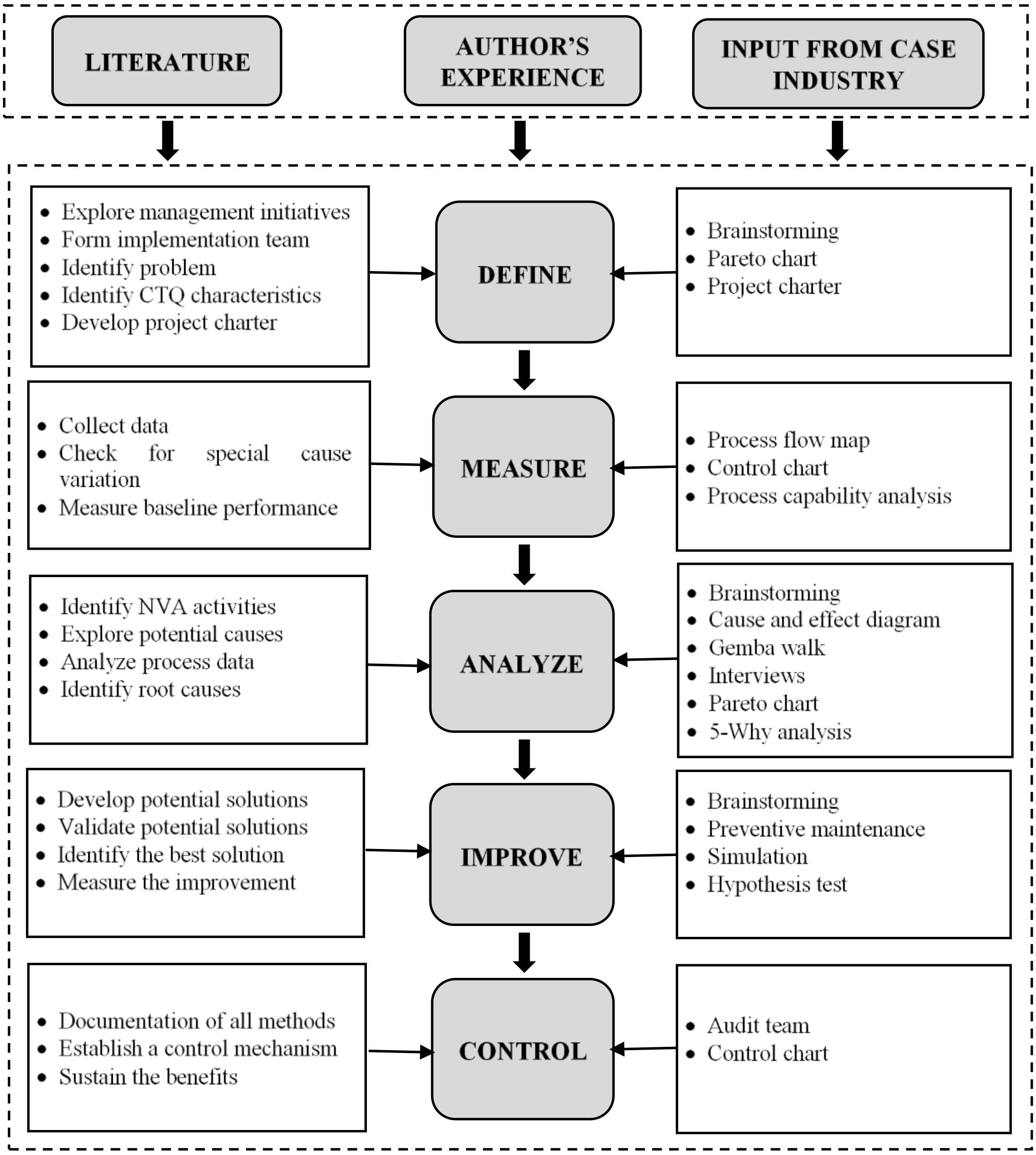

Figure 1. Proposed LSS implementation framework

The proposed framework is an integrated approach of Lean and SS. It is based on the five phases of the DMAIC methodology. The first phase of the LSS implementation framework is the 'define' phase, which aims to set the project's goal, form an implementation team, develop a project charter, and identify the critical-to-quality (CTQ) characteristics. The second phase of the LSS project is the 'measure' phase in which the required data on the CTQ characteristic is collected, and the baseline performance level of the CTQ characteristic is determined. The third phase is the 'analyze' phase, which aims to identify the factors that influence the CTQ characteristic so that the root causes of any abnormal behavior of the CTQ characteristic can be identified. The fourth phase is the 'improve' phase, which aims to generate solution alternatives and test them for all root causes identified in the analyze phase, and to implement the best solution idea in practice. The last phase of the LSS framework is the 'control' phase in which the whole process is documented, and a system is developed to ensure that the improvements made in the improve phase is sustained over time. Several tools and techniques, such as Pareto chart, process flow map, control chart, cause-and-effect analysis, process capability analysis, Gemba walk, 5-Why analysis, simulation, hypothesis test, etc. are used at different phases of the LSS framework.

4. Implementation of the proposed LSS framework

In this section, a brief explanation of the case industry is presented, the case study is conducted though the proposed LSS framework, and the findings are discussed.

4.1 Case industry

The case industry in this study is a high-tech automated metal fabrication industry producing metal cans in the United Arab Emirates. The management team of the company includes a group of experts in their areas. The company is furnished with state of the art and latest can making technology to fabricate general line cans in various shapes and sizes. The company also produces food packaging products of various types and supplies the market with progressive decorations and printing services. This study focuses on the processes used to produce three types of products such as easy-open end (EOE), tuna can and twist off cap as shown in Figure 2.

Figure 2. Case products

4.2 Case study

The proposed framework illustrated in Figure 1 is followed in this section to improve the productivity of the case industry. The LSS project is implemented through the following five steps:

4.2.1 Define phase

Initially, a meeting was conducted with the Production Manager and QA (Quality Assurance) Engineer of the case industry to set a plan and get an approval for the LSS project. Based on the discussion, a project implementation team was formed including an academician, four graduating students, and Production Manager, QA Engineer, and relevant shop-floor operators of the case industry. To identify the major problem area, the LSS team collected data and information on scarps/defectives and wastes that might affect the productivity of the manufacturing system. Based on the collected data on the scraps produced in 22-month (April 2017 - February 2020), multiple Pareto charts were constructed to define the scope of the study. As shown in Figure 3, the most frequently occurring problem is the higher number of scraps produced during the production of EOE products (about 90% scraps are contributed by the process producing EOE(73, 83) products). It is noted that two different sizes of EOE products such as (73, 83) cm and 99 cm are produced by the case industry. It is also noted that in Figure 3, the quantity of scraps of tuna can products is very small and included in “other”.

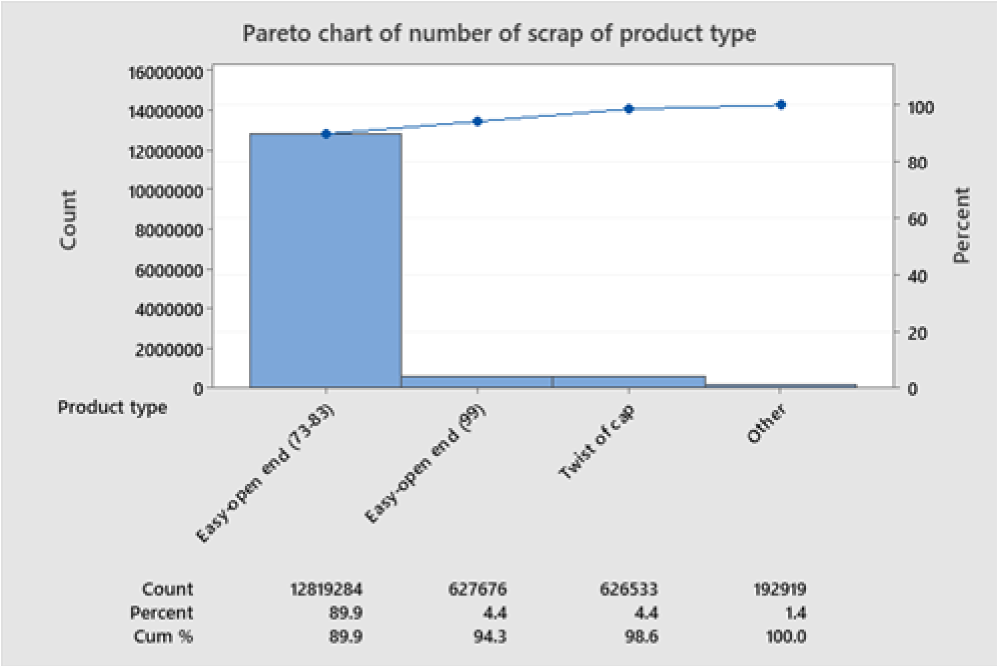

Figure 3. Pareto chart of number of scraps of product type

Finally, based on the discussion with Production Manager of the case industry, the LSS team defined the CTQ characteristic as the productivity (number of non-defective products produced per day) of the EOE(73, 83) production line to be investigated in this study.

The project charter indicated in Table 2 was also constructed in this phase to provide a brief description of the whole project including objective, scope, and expected benefit to the case industry.

Table 2. Project charter

Project title	**Improving productivity of a metal forming industry producing tin cans**				
Goal statement	Improve productivity of the process producing EOE products.				
Problem description	Low productivity due to high defective rate and long downtime of the EOE production line.				
CTQ Metric	Number of non-defective EOE products produced per day.				
Project scope	Only focuses on EOE products.				
LSS tools used	Pareto chart, process flow map, control chart, cause and effect diagram, 5-Why analysis, simulation, hypothesis tests, preventive maintenance.				
Team members	Academician, Students, Production Manager, QA Engineer, Shop-floor operators.				
Expected benefit to company	Profit improvement due to increasing the productivity.				
Expected benefit to customer	Customer satisfaction due to on-time delivery of the products.				
Project plan	Define	Measure	Analyze	Improve	Control
	3 weeks	3 weeks	4 weeks	4 weeks	1 week

4.2.2 Measure phase

To get a clear idea about the process producing EOE(73, 83) products, the LSS team investigated the production line several times. There are three "Shell" lines, one of which is offline and produces EOE(73 or 83) products whenever required, and the other two are online and produce EOE(73) products on regular basis. The offline workstation is used when there is an excess demand for EOE(73) or a demand for EOE(83) products. During the production process, the plain tinplate (raw material) is cut into shells at “Shell” workstation and moves to “Conversion Press” workstation through a “Balancer”. In “Conversion Press” workstation, keys are attached (pressed) on the shells. Next, the pressed EOE products (sub-finished EOE products) move from “Conversion Press” workstation to “Penal Ver” workstation where a layer of anti-rusting material is applied on the opening area of the EOE products, and the finished EOE products leave the workstation for packaging. It is noted that the “Balancer” connects all three “Shell” lines together as well as contains buffer trays of each type and size of sub-finished EOE products. If the “Conversion Press” workstation stops working, sub-finished EOE products from the buffer trays are sent to the “Penal Ver” workstation so that the production process continues without any interruption. The three workstations of the EOE production line and their operations are outlined below, and Figure 4 shows the process flow map of the EOE production process.

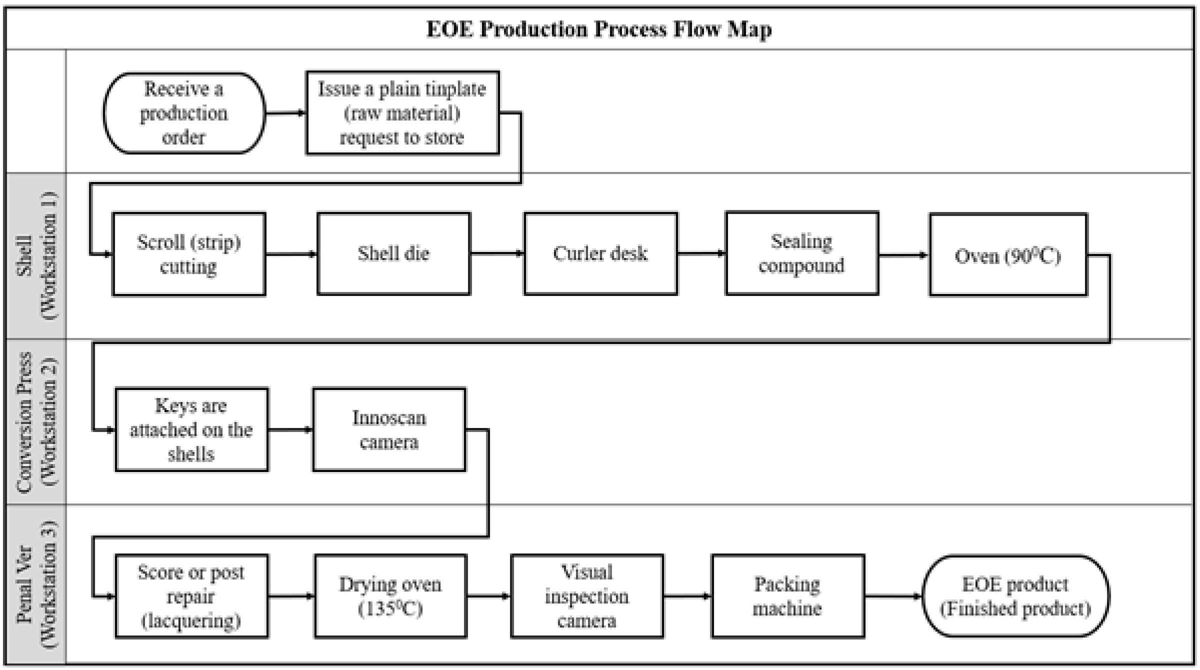

Figure 4. Process flow map of EOE production line

Workstation 1: Shell

- Scroll (strip) cutting: the strip roll (plain tinplate) is cut into individual sheets.
- Shell die: a press is used to cut and shape the raw material into the required patterns and forms (circular shells).
- Curler desk: the shells are pressed to form the edges around and on the shell surface itself.
- Sealing compound: the shell is coated with a compound to keep out air and moisture.
- Oven (90^0C): an oven is used to remove the moisture and dry the product after the sealing compound is added.

Workstation 2: Conversion Press

- Press: the required keys are pressed to the shell.

- Innoscan camera: it detects any microscopic holes available on the pressed shell's surface.

<u>Workstation 3: Penal Ver</u>

- Score or post repair (lacquering): a compound is used to coat the edges of the EOE products to prevent crusting and make it durable and resistant to damage.
- Drying oven (135^0C): it dries large patches of the final product after adding the lacquer.
- Infrared camera: it detects any defect or malfunction within the finished EOE product.
- Packing machine: finished EOE products are gathered and wrapped in boxes to be shipped.

Finally, the baseline performance of the production line producing EOE(73, 83) products was measured based on the collected 22-month data on the number of defectives/scraps and total production quantity in the define phase. Before calculating the number of non-defective products produced per day, Laney's P´ chart (Laney, 2002) for monitoring the proportion of nonconforming products was constructed to ensure that there is no special cause variation in the data (i.e. the process was statistically in-control). It is noted that the classical P chart is not applicable here as the sample size is quite large which results in very narrow control limits and produces a lot of false alarms. After second iterations (after excluding two out-of-control sample points), all sample points fell within the control limits of the Laney's P´ chart indicating that the process is in-control as illustrated in Figure 5.

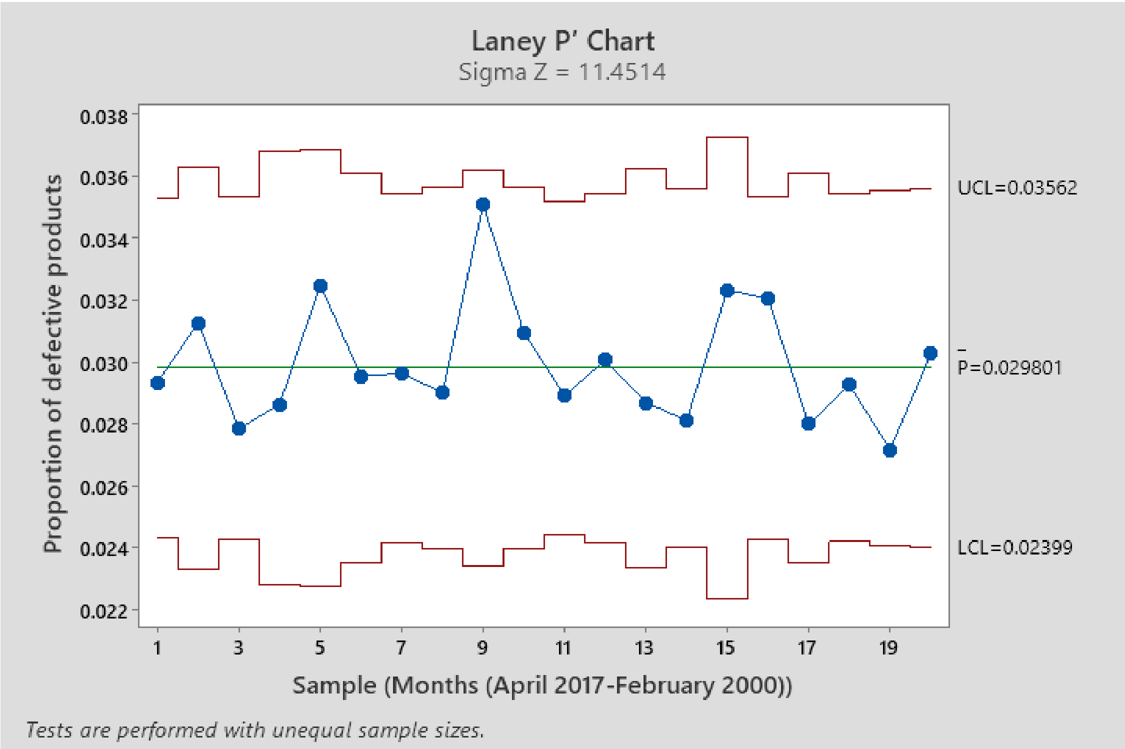

Figure 5. Laney's P´ chart

The control chart shows that, on average, about 2.9801% of the products are defective when the process is in-control (i.e. proportion of defective products is 0.029801). Thus, the PPM (defective parts per million) value of the process producing EOE products is 29,801 (= 0.029801 × 1000000). The EOE production line currently produces, on average, 949,733 products per day, and thus the daily productivity is about 921,430 (= 949,733 – 949,733×0.029801) non-defective products (i.e. the proportion of daily productivity is about 0.970199).

4.2.3 Analyze phase

The factors that are responsible for the low productivity and the related causes are analyzed in the analyze phase. The LSS team investigated each step of the production process, checked the historical records of the company, and conducted several brainstorming sessions with Production Manager, QA Engineer, and shop-floor operators to get more information about the identified factors that affect the productivity of the production line. Based on the collected data and information from the investigation, cause-and-effect diagrams were drawn as shown in Figure 6. Validation of the identified causes were then conducted by Gemba walk (Womack, 2011), historical records and/or interviews for non-measurable causes, and Pareto analysis for measurable causes. Finally, 5-Why analysis was conducted based on the validated causes to identify the root causes of the low productivity. The results of the root cause analysis are discussed below.

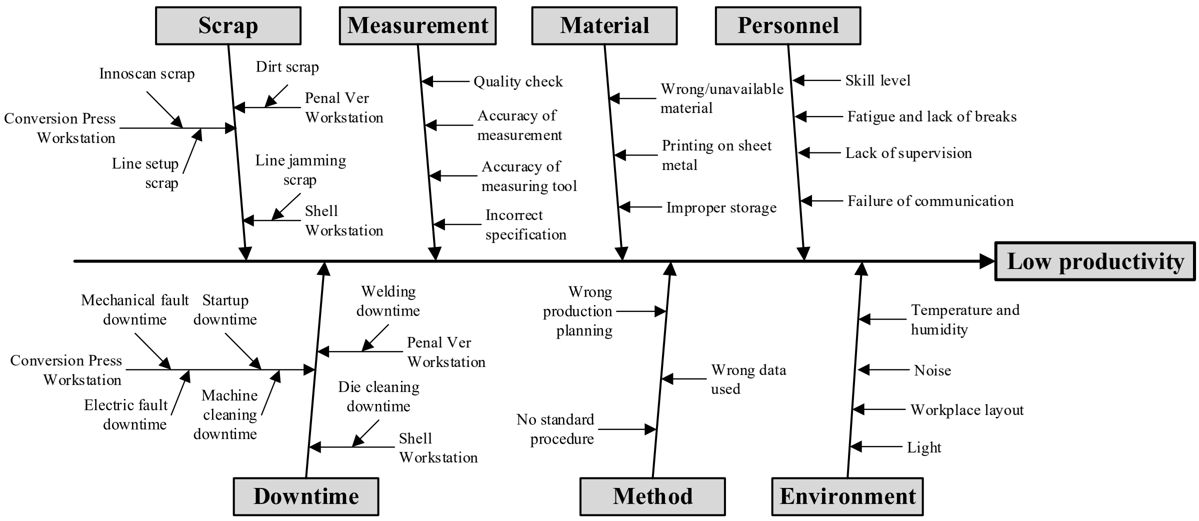

Figure 6. Cause-and-effect diagram low productivity of the EOE production line

Validation of non-measurable causes:

The validations of the non-measurable causes of the low productivity were performed by Gemba walk, historical records and/or interviews with Production Manager, QA Engineer and/or shop-floor operators, and the results are summarized in Table 3.

Table 3. Validation of non-measurable causes

Causes	Desired/Observed states	Mode of validation	Remarks
Wrong production planning	Production planning should be accurate and effective.	Interviews with QA Engineer and Production Manager	Not root cause
Wrong data used	Data used in production planning must be accurate.	Interviews with Production Manager, QA Engineer, and historical records	Not root cause
No standard procedure	Operators should consistently follow the right procedure over time.	Interviews with shopfloor operators and historical records	Not root cause
Temperature and humidity	The work environment should be comfortable.	Gemba investigation	Not root cause
Noise	Noise intensity level should be at acceptable level.	Gemba investigation	Not root cause
Workplace layout	The machines and material handling systems should be organized in a way that makes the execution of the operations effective.	Gemba investigation	Not root cause
Light	The light intensity level should be adjusted ergonomically.	Gemba investigation	Not root cause
Skill level	The operators should have an optimum skill level to perform the intended job.	Interviews with QA Engineer, shopfloor operators, and historical records	Not root cause
Fatigue and lack of breaks	The time and breaks should be determined in a way that reduce employees' fatigue.	Interviews with QA Engineer and shopfloor operators	Not root cause
Lack of supervision	The Production Manager should perform Gemba and always be available on the shopfloor during production.	Interviews with shopfloor operators	Not root cause
Failure of communication	The company should support and encourage downward and upward communication among the employees.	Interviews with Production Manager, QA Engineer, and shopfloor operators	Not root cause
Wrong/unavailable material	The required raw material should be available in the store.	Historical records	Not root cause
Printing on sheet metal	Raw sheet metal should be free of any scores or printing.	Historical records	Not root cause
Improper storage	Raw sheet metal should be stored properly to avoid any damage	Historical records	Not root cause
Quality check	Quality check for the output of each workstation should be done.	Interviews with QA Engineer, and shopfloor operators	Not root cause
Accuracy of measurement	The operator should measure the CTQ characteristics of the products carefully and accurately.	Gemba investigation and historical record	Not root cause
Accuracy of measuring tool	Measurement tools should be of high precision.	Interviews with QA Engineer	Not root cause
Incorrect specification	The production specifications should be followed accurately.	Gemba investigation, and interview with QA Engineer	Not root cause

Validation of measurable causes:

As shown in the cause-and-effect diagram (Figure 6), the measurable causes of low productivity are long downtime such as machine cleaning downtime, startup downtime, mechanical fault downtime, electrical fault downtime, die cleaning downtime, and welding downtime, and four main types of scraps such as dirt scrap, innoscan scrap, line jamming scrap, and line setup scrap (see Figure 7).

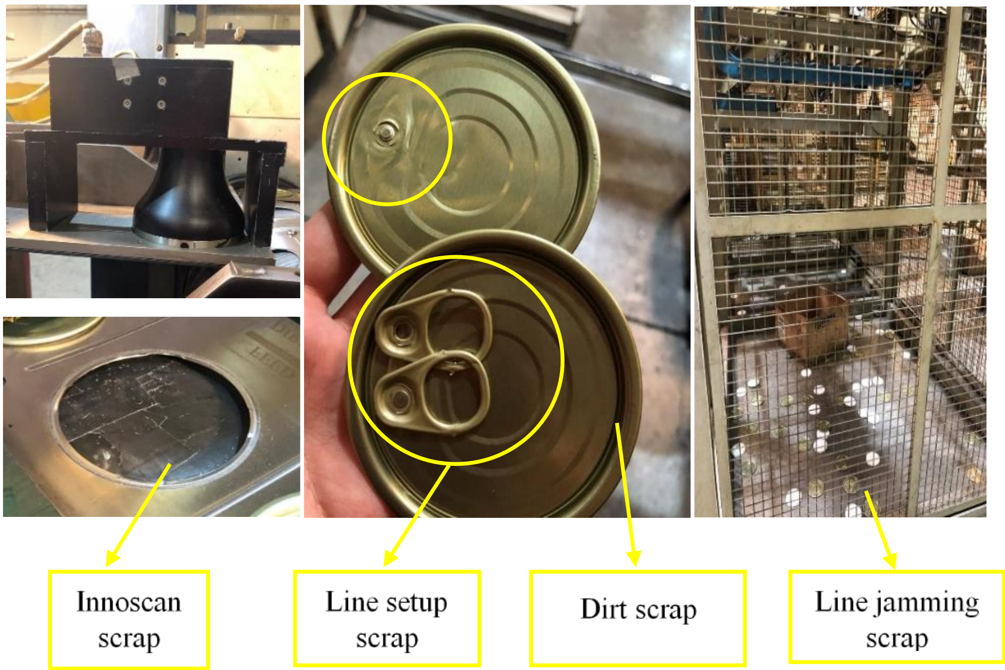

Figure 7. Four main types of scraps of EOE products

The analysis of the measurable causes was conducted based on the 22-month data collected in define phase at different workstations of the EOE production line. Pareto charts shown in Figures 8 and 9 were constructed based on the collected data to identify the most frequently occurring type of scarp and downtime that are mainly responsible for the low productivity of the production line.

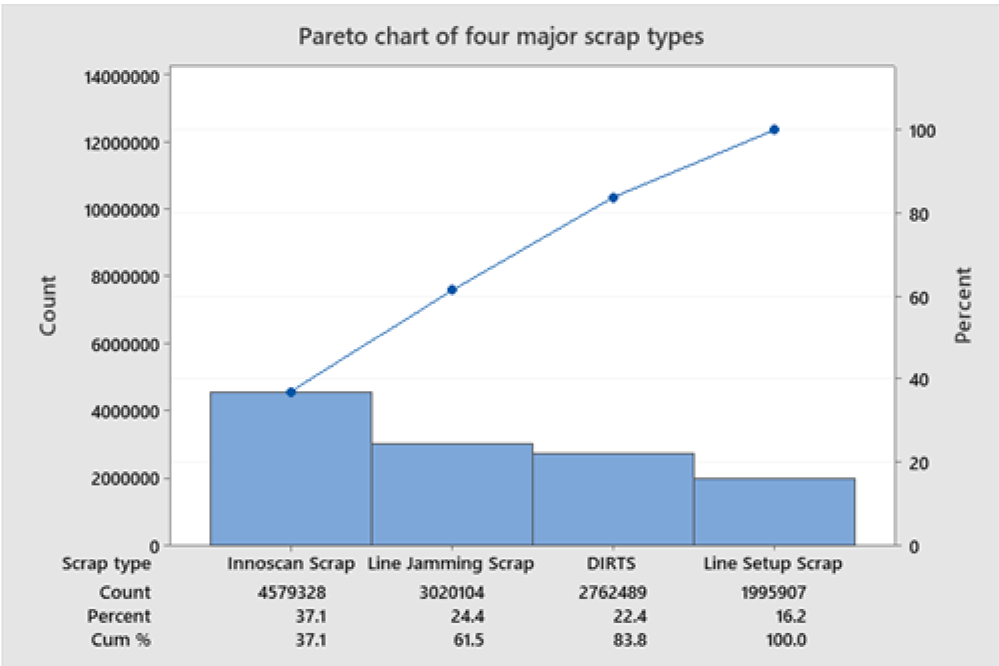

Figure 8. Pareto chart of four main scrap type of EOE products

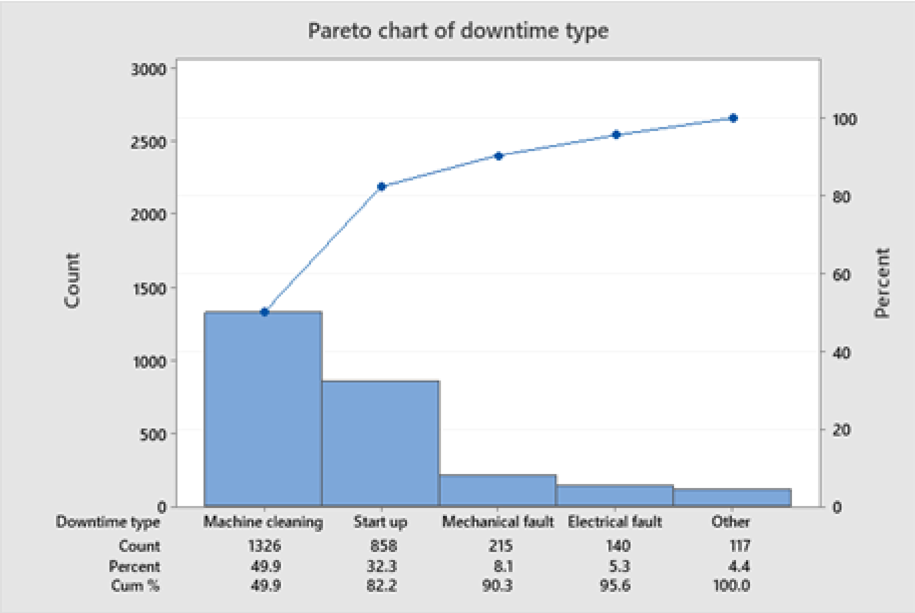

Figure 9. Pareto chart of downtimes of EOE production line

As shown in Figures 8 and 9, about 61% of the total scraps is due to innoscan scrap and line jamming scrap, and about 82% of the total downtime results from machine cleaning downtime and startup downtime. Further investigation showed that three of these four causes (innoscan scrap, machine cleaning downtime and startup downtime) are related to “Conversion Press” workstation, and the line jamming scrap is mainly produced in the “Shell” workstation, and thus, the “Conversion Press” workstation is mainly responsible for the low productivity of the production line.

Finally, the root causes behind the low productivity of the “Conversion Press” workstation was investigated by 5-Why analysis (Figure 10) with the help of Production Manager, QA Engineer, and shopfloor operators. It was found from the 5-Why analysis that currently no specific sampling plan for checking quality of incoming raw material (plain tinplate) is used, and no specific maintenance policy for the workstation is followed.

Figure 10. 5-Why analysis for low productivity of "Conversion Press" workstation

4.2.4 Improve phase

The LSS team discussed the root causes identified in the analyze phase with the Production Manager, QA Engineer, and shopfloor operators of the case industry, and recommended the following suggestions to minimize the causes of the low productivity:

- Quality of incoming raw material: to check the quality of incoming lot of the raw materials, the QA department usually collect samples from the lot randomly and conduct a visual inspection without following any specific inspection plan. The innoscan scraps are mainly due to the microscopic holes in the raw plain tinplate, which is not possible to identify by visual inspection. The LSS team suggested to follow an appropriate sampling plan and conduct lab test so that the quality of the incoming lot can be maintained.

- Maintenance: currently the maintenance of the workstations is not performed regularly. The maintenance is usually performed if the production is interrupted, for example, if there is any machine breakdown or any other mechanical fault such as line jamming occurs. The LSS team suggested to follow a preventive maintenance policy (mainly cleaning activities) so that the maintenance of the workstations (specially "Conversion Press" and "Shell" workstations) is initiated on regular basis, which in turn may reduce the cleaning and start-up downtimes.

The recommendations were highly appreciated by the company. However, long-term planning and management commitment are needed to implement them. In this phase, simulation was used to check the impact of following a preventive maintenance policy on the productivity of the production line. Simulation is widely used as an effective and inexpensive tool for process improvement (Bhat *et al*., 2014; Khan *et al*., 2020). Based on the process flow map (see Figure 4), a simulation model was developed using ARENA Simulation software as shown in Figure 11. The in-control 20-month data on production quantity, scrap quantity, downtime, and other required information collected from company's historical records in the measure phase were analyzed using ARENA input analyzer and the input parameters required for the simulation model were determined. The developed original simulation model was then tuned-up and verified by the Production Manager of the company.

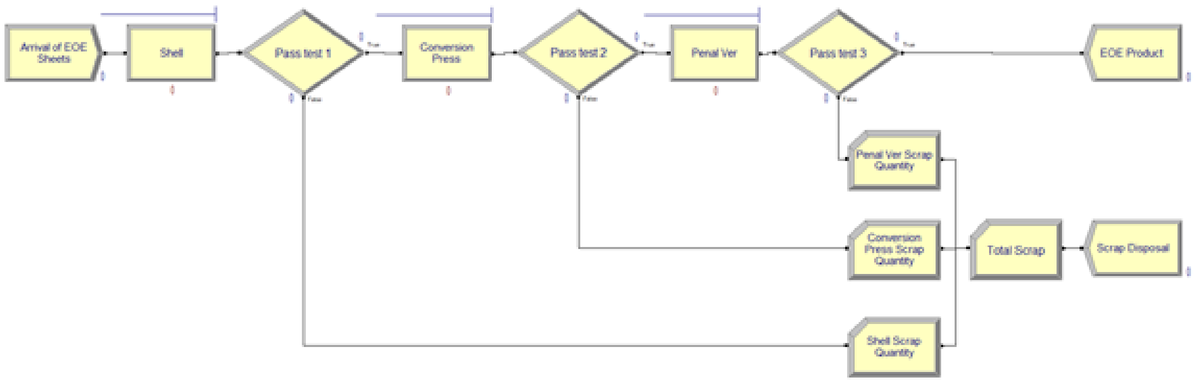

Figure 11. Original simulation model of the EOE production line

The original simulation model was run for 40 days, and the proportion of daily productivity (proportion of non-defective products produced per day) were calculated. The data collected from the company were then used to validate the simulation model through tests of hypotheses. Since the data on the productivity are discrete, a one-sample hypothesis test for the proportion (z-test) of the daily productivity was performed (H_1: $p \neq 0.970199$). The test results show that the proportion of daily productivity (p-value = 0.761) is not statistically different from those of the original production line.

Several studies (Ahuja and Khamba, 2008; Sing *et al*., 2013; Daily and Peterson, 2017) showed that a preventive maintenance schedule using Standard Operating Procedure (SOP) tool helps considerably in standardizing all cleaning activities, which results in consistency in work done and may be able to reduce the cleaning and startup downtimes and scrap rate significantly. The LSS team proposed a preventive maintenance (mainly cleaning activities) plan for one hour a day for the EOE production line. Based on a one-week pilot study, the Production Manager suggested a 10% reduction in the downtime. The validated simulation model was then modified considering the suggested cleaning activities to be performed for one hour a day. The modified simulation model was then run for 40 days, and the data of the productivity were analyzed following the same procedure used in the measure phase. The results show that on average, the daily productivity of the production line was increased by 1641 non-defective products (daily productivity increases from 921,430 to 923,071 and PPM value reduces from 29,801 to 29,551) after following the porposed maintenace policy. Consequently, the overall yearly productivity can be increased by 511,992 (= 1641 × 26 × 12), which is equivalent to an increase in yearly sales of about $25,600 ($0.05/piece). It is noted that following a maintenance policy on regular basis not only reduces the downtimes, but also reduces the scrap rate of the production line substantially. However, the reduction in the scrap rate was not considered in the simulation study as it was quite difficult to estimate the reduction in the scrap rate accurately, given the short length of the pilot study. Consequently, the actual reeduction in the PPM value and the improvement in the productivity are expected to be much higher than the calculated value.

4.2.5 Control phase

This phase is the last step of the DMAIC methodology, and the objective of this step is to make sure that the improvement obtained in the Improve phase is sustained over time. All the procedures followed in the study, along with the suggested solutions were documented for the future use. An audit team including QA Engineer and shop-floor supervisor was formed to investigate the production line, especially maintenance activities over time. The audit team is also responsible to submit a performance report every month to the Production Manager who in turn, should have at least one meeting per month with all process stakeholders to discuss the results and identified issues. It was suggested to use Laney's P′ chart for continuous monitoring of the proportion of the defective products produced by the process so that instant actions can be taken if any out-of-control status is detected. In addition, a continuous employee development program was recommended so that the employee can be trained and kept up to date with the latest technology over time.

5. Lessons learned

The systematic LSS framework proposed in this study for improving the productivity was highly appreciated by the management of the company. The management was motivated to implement more LSS projects in other departments for effective utilization of resources and minimizing waste. The major difficulties faced during the implementation of the project was during the collection of required data from historical records as the data were not recorded in a systematic way. In addition, it was not easy to interview the operators/supervisors as the production continues for 24 hours, and the operators/supervisors are busy most of the time. The main lessons learned from the implementation of the proposed LSS framework are:

- A systematic LSS framework using DMAIC methodology can successfully be used as an effective approach to tackle the problem and generate solutions.
- Simulation is an effective tool in studying the behavior of the system and applying any suggested improvements without interrupting the actual system.
- Top management support and employee involvement are very important in successful application of a LSS project. Employee motivation is another important success factor of LSS initiatives.
- The implementation of the LSS project improved the employees' awareness of their responsibility towards productivity and quality.
- The introduction of LSS methodology to the employees before its implementation is very crucial as most of the employees do not have any knowledge about the LSS methodology.

6. Conclusions and future work

The LSS is a popular business process improvement strategy widely used to promote business and operational excellence in manufacturing and service organizations. This study proposed and followed a systematic DMAIC-based LSS framework to improve the productivity of a metal can manufacturing industry. The deployment of the proposed LSS framework improves the annual productivity of the production line by about 511,992 non-defective products, which is equivalent to an annual increased sales of about $25,600. The improvement is achieved by employing several tools and techniques such as Pareto chart, process flow map, control chart, cause-and-effect diagram, 5-Why analysis, simulation, Gemba walk, brainstorming, preventive maintenance, and hypothesis tests through the proposed LSS framework. The improvement is expected to enhance customer satisfaction, minimize production cost, and maximize company's goodwill and profit. In the current study, the effectiveness of the proposed solution approaches was tested by simulation. It will be interesting if a future work can investigate the impact of the proposed solution approaches on the actual system. In addition, a cost-benefit analysis might be used to highlight the benefit of implementing the DMAIC-based LSS framework in the organization.

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