

# Manufacturing conversion cost reduction using quality control tools and digitization of real-time data

Veer Shivajee <sup>a</sup>, Rajesh Kr Singh <sup>b,\*</sup>, Sanjay Rastogi <sup>a</sup>

<sup>a</sup> Indian Institute of Foreign Trade (IIFT), Delhi, India

<sup>b</sup> Management Development Institute, Gurgaon, India

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## ABSTRACT

Two-wheeler automobile manufacturers in India are currently facing a big pressure to reduce the overall manufacturing cost in order to sustain the position in hypercompetitive domestic and global market. The manufacturing conversion cost is one part of the overall manufacturing cost. It consists of three major components i.e. product or parts scrap cost, consumables cost and tool cost. The scrap cost is the cost of defective products, which are not produced in accordance with standard and can't be sent to market. The consumables cost is the cost of other than basic raw material used in manufacturing i.e. filters, filler materials, fuel, gases, chemical, coolant and lubricants etc. This study has tried to emphasise role of conversion cost in making organisations cost competitive. Case study-based approach is used in this study. The case manufacturing system comprises three main processes: machine shop, frame plant (weld and paint shop) and assembly shop. In frame plant, paint shop and weld shop are the two main sub sections of this automobile manufacturing. More than 50% of overall manufacturing conversion cost is consumed in these two areas. This study attempts to illustrate the reduction of the manufacturing conversion cost by prioritizing and analysing the cost factors using DMAIC (define-measure-analyze-improve-control) approach using quality control (QC) tools like Pareto chart, Cause & effect diagram and digitization of real time data. Authors have identified eighteen elements of conversion cost in this study. It has been observed from this study that even small saving in conversion cost per vehicle i.e. INR 24.18 (0.35 US\$) per vehicle has resulted in annual saving of 2.2 million USD. Initiatives taken by this organisation for cost saving has also resulted in cleaner production and more sustainable manufacturing processes. Findings will be motivating to other manufacturers for reducing manufacturing cost using QC tools on smaller and insignificant activities.

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## 1. Introduction

In last one decade, the two-wheeler automobile market is growing rapidly not only in China and Thailand but in India as well. 19.9 million Two-wheelers were sold in India during fiscal year 2016–17. The two-wheeler automobile sector is growing very fast and has become a key player for GDP in the global and Indian economy (Singh, 2017). India is now the biggest two-wheeler manufacturer in the globe with overall growth rate of 89.5 percent during the period of 2010–2017. The automobile exports from India increased 15.81 per cent and two-wheelers exports increased 20.30 per cent during same period (SIAM, 2017).

Automobile manufacturing is considered as an important industry for sustainable economic growth of country (Gopal and Thakkar, 2016). Due to the upsurge in the two-wheeler market demand in the era of Industry 4.0 (Bortolini et al., 2017), automobile manufacturers are continuously integrating new technologies in the manufacturing process to offer innovative products to customers and reaping high sales. The technological changes in manufacturing system reduce manufacturing costs and improve machine productivity (Baumers et al., 2016). The performance of the firm can be evaluated and improved on the basis of cost, manufacturing processes and marketing capability (Kushwaha and Sharma, 2016). Singh et al. (2017) have observed that zero-manufacturing waste control could be roadmap for the future of advanced manufacturing systems.

The global leaders in two-wheeler manufacturer segment are coming to India with innovative technologies and giving tough

\* Corresponding author.

E-mail address: [rksdce@yahoo.com](mailto:rksdce@yahoo.com) (R.K. Singh).

competition to existing manufacturers by producing at low manufacturing cost. The electric vehicles (EV) market is also set to see the new models from new manufacturers of foreign origin and home grown (Dhar et al., 2017). Banker et al. (1995) have observed that organisations traditionally focused on manufacturing overhead cost and ignored other cost components during manufacturing. Most of the costs of manufacturing processes are calculated as a projection in development phase (Murat and Yusuf, 2009). However, at the time of product development, organisations plan to reduce the cost of a product at the design stage rather than at the manufacturing stage (Shehab and Abdalla, 2001). It is also emphasised to estimate the product manufacturing cost during the early design stages (Tao et al., 2018). This cost can be addressed through the process innovation (Hervas-Oliver et al., 2014) when it is difficult to address the cost at designing stage. In order to be competitive, organisations have to improve the traditional production system and cost management with the adaptation of innovative technologies (Murat and Yusuf, 2009).

The cost control management is being done through technological innovations to increase performance even by small manufacturing companies (Singh et al., 2017). Organisations are also focusing on sustainability and competitiveness (Van Ark, 2008). Most of the costs of manufacturing processes are calculated as a projection in development phase (Murat and Yusuf, 2009). The manufacturing cost reduction is also being done through implementing Single-minute exchange of die (Dillon and Shingo, 1985; Cakmakci, 2009). The manufacturing cost reduction is the only way to be more sustainable and competitive in current business environment.

### 1.1. Problem description

The automobile sector is a key player in growth of global and Indian economy. The global motor vehicle industry contributes 5 per cent directly to the total manufacturing employment, 12.9 per cent to the total manufacturing production value and 8.3 per cent to the total industrial investment (Organisation Internationale des Constructeurs d'Automobiles, 2006). It contributes 7.1% to GDP and provides employment to 22 million people directly or indirectly and contributes 13% to excise revenue in India (SIAM, 2017). The production of two-wheeler in India is in increasing trend and highest among all the automotive sectors as shown in Fig. 1.

In spite of big volume of two-wheeler production, very few studies have tried to analyse impact of conversion cost savings in overall manufacturing cost for this sector. Therefore, main objectives of this study are:

- To identify elements of manufacturing conversion cost across different processes in automobile sector.

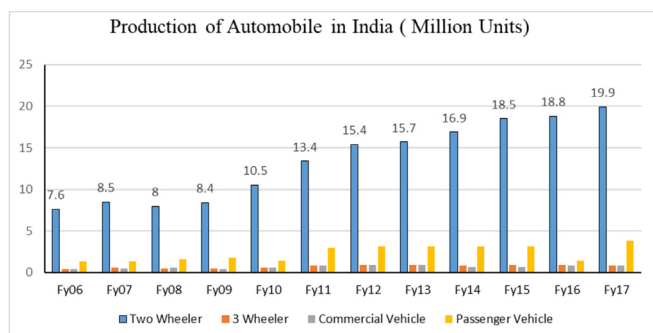


Fig. 1. Production of automobile in India (Units in millions) - Source SIAM, 2017.

- To identify appropriate quality control and IT tools for reduction of manufacturing conversion cost.
- To analyse impact of different initiatives in overall saving of manufacturing cost.

The rest of paper is organized as follows. The section two is on literature review for cost elements. The section 3 gives the business description and profile of the case company. Section 4 gives the description of the research approach and framework for study and section 5 discusses the results respectively. Finally, conclusion and future scope are presented in Section 6.

## 2. Literature review

Origin of refined and detail versions of the manufacturing conversion cost were emphasised during development of first industrial revolution (Parker and Fleischman, 2017). At the beginning of the 20th century i.e. second industrial revolution, electricity was introduced and it became the primary source of energy (Stearns, 2018). It was very convenient and very cost effective to use electricity in manufacturing rather than water and steam (Rud, 2012). The second industrial revolution also saw the introduction of number of management improvements programs that reduced the manufacturing cost by increasing the manufacturing efficiency and adding new manufacturing facilities. The manufacturing cost saving scope is still there as the second industrial revolution has yet to be fully experienced by 17% of the world as nearly 1.3 billion people still lack access to electricity (Schwab, 2017).

The third industrial revolution not only created new products and whole new manufacturing industries but also reduced the manufacturing cost by revitalizing traditional industries through innovative technologies. The third industrial revolution changed the way of manufacturing by introducing the new tools, computers and robots (Greenwood, 1997; Rifkin, 2011; Schwab, 2017). The use of automated material handling, programmable logic controller (PLC) machines & equipments were used to improve the productivity drastically and organisations were able to reduce the manufacturing cost. The Robots in manufacturing system took the place and caused biggest reduction in manufacturing cost (Mathew and Kathawala, 1988). Robotics made the labour free from hazardous and repetitive tasks, which were impacting ergonomic conditions (Wang et al., 2017).

According to Hoover et al. (2002), manufacturing's system needs to be efficient to attain cost effectiveness in its operations. All past three industrial revolutions in manufacturing industry, resulted in a breakthrough changes in society (Schuh et al., 2014; Schwab, 2017). The current industry revolution "Industry 4.0" is still vague in context of cost saving and productivity improvement in context to many Indian organisations. The traditional cost estimation approaches have considered only the costs in production phase and disregarded the other costs like rework and rejection or other waste cost. These cost gives huge impact on business sustainability and competitiveness (Schaltegger and Wagner, 2017). The cost of manufacturing processes can be optimised by using very famous techniques such as just-in-time technology (JIT), activity-based costing (ABC), balanced score card, total quality management (TQM) and business process reengineering (Blocher et al., 2002). According to Patxi (2018), to keep manufacturing lean and to make it cost effective, we have to emphasise on the flow of materials from beginning of manufacturing until it is completed. The manufacturing conversion cost can be reduced by eliminating quality defects which may occur during manufacturing processes. The quality control tools can be applied in process improvement during production (Sharma and Suri, 2017). Thomas and Barton (2006) focused on cost-effective approach for Six Sigma project

execution by employing simple tools like Pareto chart (Bajaj et al., 2018) and Cause & Effect diagram for identifying manufacturing process deficiencies (Shainin and Shainin, 1988).

All the manufacturing organisations are working aggressively to reduce manufacturing costs for being more competitive in terms of cost reduction (Brigham and Houston, 2012). The innovative technologies in manufacturing under this industrial revolution make it possible without laying off workers and implementing any drastic cost-cutting measures. Now organisations treat people as company assets (Pfeffer and Veiga, 1999). The organisations are thinking big changes in business for getting instant big profit while ignoring small cost saving in operating manufacturing cost. Real-time monitoring of small variable cost of business and quality control tools can help any industry in reducing variable cost in terms of consumables, energy resources and product rejection (Farooq et al., 2017).

This paper emphasises that how the manufacturing processes waste and consumables are a big source of cost saving in long run when industries are having mass production (Wang et al., 2017). The manufacturing cost can be reduced by optimizing the process parameters and simultaneously optimizing the dimensions of product on basis of performance (Haghighi and Li, 2018) in existing manufacturing processes. The cost optimization is one of the significant competitive dimensions which every organization wants to control at the lowest level. The manufacturing cost is optimized in the plant effectively by controlling parameters like inventory size, inventory replenishment period and cost. These parameters can be improved by implementation of 5S activities (Randhawa and Ahuja, 2018). As per Iwańkiewicz and Taraska (2018) assembly shop is one of the very important process in manufacturing, which can give big impact in manufacturing cost reduction by integrating digitization with mass production assembly line (Yin et al., 2018).

The automation through digitization in manufacturing promise numerous benefits such as reduced part cycle time, lower defect rate, higher quality and reliability, reduced waste (Ghobakhloo, 2018). It helps further to save labour costs, increases production, and ensures quality. Digitization in manufacturing denotes a highly productive manufacturing environment of connected and intelligent machines and processes where rejection, defect, and, downtime is minimized (Ghobakhloo, 2018). The traditional industry transformation through digitization e.g. Internet of Things (IoT) (Tao et al., 2014; Jing et al., 2014; Chen et al., 2015), wireless sensor networks (Qiu et al., 2006), big data (Chen et al., 2014), SCADA system (Figueiredo and da Costa, 2012), and SAP system (Lodh and Gaffikin, 2003) can be done to improve manufacturing process efficiency (Parviainen et al., 2017). The Integration of digitization in traditional factories is being done to get cost advantages (Wang et al., 2016; Kusiak, 2018). Additive manufacturing (AM) is now a days, being adopted which has the potential to reduce manufacturing cost, material waste, and energy usage (Laureijs et al., 2017).

Machining is one of the major manufacturing processes, which can be improved by application of statistical techniques in solving an issue of major product rejection and rework because of machining process variation (Gijo, 2005). The process capability of machining process can be evaluated to bring down the rejection and rework. A step by step approach must be adopted by the application of several statistical techniques i.e. design of experiments for solving process problems (Jung, 2002). New technologies like dry machining are being introduced in operations (Sreejith and Ngoi, 2000). These are costlier than existing wet processes and it could be biggest challenge for two-wheeler automotive industries in terms of conversion cost reduction. A new method to predict tool-wear and tool-life performance in dry machining can be

improved by extending a Taylor speed-based dry machining equation (Marksberry and Jawahir, 2008). To improve the existing machining process in terms of tool cost reduction, machining process needs to improve in terms of high material removal rate, good work surface finish and low tool wear. These objectives of machining processes can be achieved by reducing tool wear by using proper cooling system of the tool during machining (Mia et al., 2018). The tools can be modified to flow liquid nitrogen as coolant through a canal made in the tool so that liquid nitrogen can be directly applied to the machining zone during machining (Khan and Ahmed, 2008).

Tortorella et al. (2018) have discussed the implementation of lean in manufacturing for reduction of cost and waste. Prashar (2018) has observed that Small and Medium Enterprises can save cost by eliminating liquidated damages using quality tools; failure mode and effect analysis; lean six sigma etc. Chhabra et al. (2017) have observed that automobile organisations can become competitive by exploring sustainable manufacturing processes and using consumables such as carbon positive packaging. The optimal batch size is the one way to reduce variability in the manufacturing process for minimising production system costs (Tayyab and Sarkar, 2016).

The product waste can be reduced by improving product quality through innovations in process and product (Jaumandreu and Mairesse, 2017). The seven basic quality tools i.e. cause-and-effect diagram, check sheet, control charts, histogram, pareto chart, scatter diagram and stratification are very effective in reducing the process deficiencies (Tague, 2004). For instance, it is not possible to maintain a cleaner production program with a lack of investigations and without using well-known tools such as Quality Control (QC) Tools in production system (Silva et al., 2013).

Most of researchers focused on major technological changes or adoption of new technologies like Additive manufacturing (AM) to get cost benefit in manufacturing system (Bartodziej, 2017; Costabile et al., 2017). Many manufacturing strategies are centred on the traditional concepts of focused manufacturing capabilities such as quality, cost, dependability, flexibility and innovation (Corbett and Claridge, 2002). This paper will explore how small improvements and changes can reduce the conversion cost without much investment in complete manufacturing system of a high production manufacturing organisation.

## 2.1. Elements of manufacturing cost

The manufacturing cost is overall expenses of all resources consumed in the process of manufacturing a product from raw materials to finished products. As shown in Fig. 2, manufacturing cost can be classified into three main categories i.e. raw material cost, labour cost and manufacturing conversion cost. The elements of production cost are material cost, labour cost and other expenses (Xu et al., 2012). Most of the researchers have studied on material cost and labour cost but very few studies are available on production expenses i.e. manufacturing conversion cost. The manufacturing cost as a whole is broadly divided into three components i.e. direct material cost, direct labour cost and manufacturing conversion cost (Xu et al., 2012; Dhavale, 1990).

### 2.1.1. Direct material cost

Direct material cost in manufacturing is considered as the cost of the raw materials and components used to make a product. The direct material cost is one of the major variable costs considered in the manufacturing process (Thomas, 2016). The organisation accountants have realized that traditional cost saving techniques like standard cost cutting on raw material and manpower etc. have become out of date in today's competitive environment (Neely

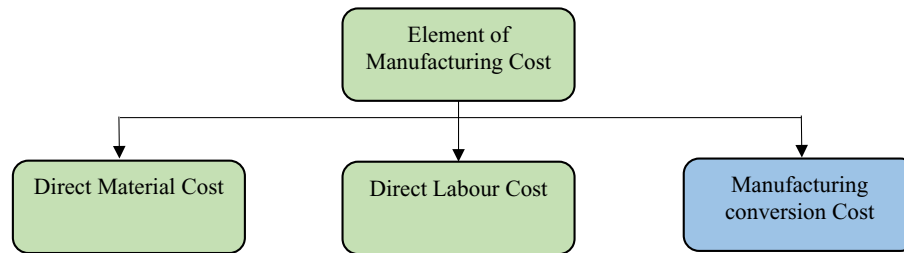


Fig. 2. Basic Elements of production or manufacturing Cost.

et al., 1995). The main task of reducing material cost has become priority for being more cost competitive. Suppliers are having challenges as a result of this pressure. New approaches are being developed to address the reduction of materials costs (Schroeder et al., 1986).

#### 2.1.2. Direct labour cost

The cost of labour comprises of wages, benefits and expenses paid to employees Jardim et al., (2017). The cost of labour is divided into two sub cost direct and indirect costs. The use of robots, automated material handling, digitally controlled manufacturing system causes biggest reduction in manufacturing cost (Mathew and Kathawala, 1988). Labour used in manufacturing, is one of the most substantial operating costs. According to Dhavale (1990), in a conventional job production, direct labour cost contributes from 20 to 40 percent of the total manufacturing cost. Operating a manufacturing plant in a very high labour cost environment faces big challenges for manufacturing industries to achieve a competitive advantage.

#### 2.1.3. Manufacturing conversion cost

This is the cost which is not focussed so much by researchers and scholars. Industries also kept it in least priority after considering material and direct labour cost. To remain competitive in the existing markets be it local or global, companies need to shift the paradigm and focus from traditional working to modern innovative approaches (Farooquie et al., 2012; Wang et al., 2015). According to Groth and Kinney (1994), manufacturing conversion cost consists of three big costs i.e. product or parts scrap cost, consumable cost and tool cost. The scrap cost is the cost of defective products, which are not produced in accordance with standard and can't be sent to market. The consumable cost is the cost of other than raw materials which is used in manufacturing i.e. filters, filler materials, fuel, gases, chemical, coolant and lubricants etc.

### 3. Research methodology

In this research, authors will explore initiatives to reduce the manufacturing cost by analysing the real time data of manufacturing consumables cost and product waste cost using quality control tools through a case study-based approach. An Indian two-wheeler manufacturing organisation is considered for this study. Different steps followed in case study are mentioned in Table 1 (Eisenhardt, 1989).

The Case research is considered as an effective research methodology for analysis and understanding of issues in fast changing markets. There are many challenges in conducting case-based research for an Original Equipment Manufacturer (OEM) (Singh et al., 2016). The case research is very time consuming, it needs competent interviewers, and data has to be collected and analysed. The conclusions are to be drawn carefully from a selected set of cases with rigorous research. The results of case research of select organisation can have a very high impact. Many researchers have used case study approach for their research study in different context (Singh et al., 2018; Chhabra et al., 2017; Taylor et al., 2004; Gunasekaran et al., 2001). The phenomenon of defined issues can be studied in practical way by case research. The case method allows the questions of 3W (Why, When, What) with full understanding of relative nature and complexity of issues. This study is based on several visits to select case company and multi-layer discussion with concerned executives of the manufacturing organisation. The literature review also helped in the identification of various issues related to manufacturing cost and its determinants. Discussions with executives helped us to identify different cost determinants in a real scenario. The information and real time data were collected for analysis through annual reports, control charts, inspection reports, tracking sheets of processes and discussion with line managers of various sections during regular scheduled visits. After identifying the case organisation and problem identification, data have been analysed by DMAIC (Define-Measure-Analyze-Improve-Control) and different quality control tools.

**Table 1**  
Case study methodology (Eisenhardt, 1989).

| Steps                             | Comments                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1-Definition of research question | To identify the determinants of manufacturing cost which are impacting organisation performance in long term.                                                                                                                                                                                                                                                                                                                                                |
| 2-Objective                       | The case research methodology will seek answers to following questions <ul style="list-style-type: none"> <li>• To identify elements of manufacturing conversion cost across different processes in automobile sector.</li> <li>• To identify appropriate quality control and IT tools for reduction of manufacturing conversion cost.</li> <li>• To analyse impact of different initiatives in overall saving in manufacturing cost of a company</li> </ul> |
| 3-Selection of the case           | Organisation is selected on the basis of its production volume                                                                                                                                                                                                                                                                                                                                                                                               |
| 4-Crafting research instruments   | A structured real time data analysed with help of quality tools like Pareto and cause & effect diagram.                                                                                                                                                                                                                                                                                                                                                      |
| 5-Approaching the organisation    | Concern senior management of organisation was contacted and permission was taken for the study, then data collection was done using daily reports, interviews and observations, etc. Multiple respondents were one to one interviewed to get a better understanding of manufacturing conversion cost.                                                                                                                                                        |
| 6-Analysing the data              | Information and data collected from organisation were analysed with help of quality tools like Pareto and cause & effect diagram.                                                                                                                                                                                                                                                                                                                            |

**Table 2**  
DMAIC steps, key tools, Quality Control (QC) tools and Digitalization matrix.

| S.No | DMAIC Steps (Soković et al., 2006)                                                                                                          | Key Tools (Prashar, 2014)                                                                                                                                       | Quality Control (QC) Tools                                                                                                                                                                                                                      | Digitalization                                                                                                                                                                   |
|------|---------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | Define- By identifying, prioritizing and selecting the right project, customer, quantified objection, scope and necessity of project.       | Project Charter, CTQ Tree, SIPOC                                                                                                                                | Pareto Diagram- to prioritize problems on a bar graph in descending order. Stratification-It separates data collected from different sources so that patterns can be seen.                                                                      | Dashboard display of all parameters and selection of most deviated parameter which is impacting the business performance.                                                        |
| 2    | Measure-key process characteristic, the scope of parameters and their performances, Identify and measure the matrix and link with business. | "As is" Process Map, Measurement System Analysis (MSA), Data Collection Plan, Baseline Sigma, Capability Analysis                                               | Check Sheets- for collecting and summarizing data, Histogram-to plot set of frequencies and evaluation the data distribution, Scatter diagram-to make relation between two or more variables. (Tague, 2004)                                     | Noval Sensor technology (Iwankowicz and Taraska, 2018), Human Machine Interface (HMI), SACADA system, supervisory control and data acquisition (SCADA), Internet of Things (IOT) |
| 3    | Analysis-by identifying gaps, key causes, obstacles and process determinants, improve by changing the process and optimizing performance,   | Brainstorming, Cause and Effect diagram, Pareto Analysis                                                                                                        | Histogram- to plot set of frequencies and evaluation the data distribution. Cause-and-effect diagram-Identifies many probable causes for problem by brainstorming the 4M (Man, Machine, Material and Methods), Scatter diagram, Pareto Diagram. | Data from multiple sensors within the production process can be analyzed to produce an assessment of product quality                                                             |
| 4    | Improvement-by key task to implement, changing the process and optimizing performance, evaluate the effectiveness of changes                | Counter Measure Matrix, Impact/Effort Matrix, Solution Prioritization Matrix, Process Failure Mode Effect Analysis (PFMEA), Implementation Plan, Cost & Benefit | Control charts-Control charts are used to study the variation and stability of process. Impact of change in 4M conditions can be evaluated. Histogram and Stratification                                                                        | Digitalization, a key enabler of Industry 4.0, can be used for improvement through an improvement cycle (Buer et al., 2018)                                                      |
| 5    | Control-Control risk, scope, schedule and cost. Presenting closure report and ensure sustainment and gain.                                  | Control Plan, Control chart                                                                                                                                     | Control charts, Histogram and Scatter diagram                                                                                                                                                                                                   | Real time process parameter monitoring and controlling through online statistical process control                                                                                |

### 3.1. DMAIC and quality control tools

The DMAIC (define-measure-analyze-improve-control) integrated with Quality Control (QC) tools and digitization has been used for analysing conversion cost data. Steps of DMAIC and its integration with QC tools are further described in Table 2. Sahoo and Tiwari (2007) used DMAIC based problem solving approach to optimize the process variables of radial forging. Soković et al. (2006) used DMAIC approach for reducing the process deficiencies and developed a new process flow. Problem solving approach like DMAIC has been one of the most successfully used techniques by many manufacturing organisations (Silva et al., 2017). It is not always necessary to use complex techniques e.g. The Figure of Eight Method (Prastyo et al., 2017), IDEA (Investigate—Design—Execute—Adjust), 8D (Bicheno and Holweg, 2009), RADAR (Soković et al., 2010) and PM analysis (Vardhan et al., 2015) to solve operational problems in manufacturing processes. Sometimes, simple tools and techniques can yield better results. Silva et al. (2013) used seven basic quality control tools and PDCA approach in order to successfully implement and maintain a cleaner production (CP) program. Silva et al. (2017) implemented a cleaner production (CP) using plan-do-check-action (PDCA) and quality tools and reduced Cans Loss Index (CLI) of case organisation. Kumar et al. (2006) used the DMAIC methodology to enhance the bottom-line results and win customer loyalty by reducing the final product defects. The DMAIC methodology combines the variability reduction tools and techniques from problem solving with the waste and non-value-added elimination tools and techniques to generate cost savings to the bottom-line of a manufacturing plant (Kumar et al., 2006).

## 4. Case illustration

As a first step, case organisation is identified and all the manufacturing cost elements are defined as given in Table 3. In second step, the real time data of processes collected on real time basis with the help of SCADA and SAP are analysed as shown in

Fig. 7. In third step, some of quality tools i.e. Pareto, check sheets and Cause & Effect diagram have been used for data analysis to find out the root causes of high manufacturing cost. In fourth step, the results after improvements are checked and if no improvement observed same cycle has to be repeated (see Table 4).

### 4.1. Profile of the case organisation

XYZ Ltd. is an automotive two-wheeler manufacturing company north India. The company has its vision of a mobile and an empowered India, powered by its two wheelers. XYZ Ltd., as a company's new identity, reflects its commitment towards providing world class mobility solutions with renewed focus on expanding company's footprint in the global arena. The company has a market share of about 46% in the two-wheeler category. On 31 March 2013, the market capitalisation of the company was 4400 million US \$. During the 1980s, the company introduced motorcycles that were popular in India for their fuel economy and low cost. In 2001, the company became the largest two-wheeler manufacturing company in India and globally. It maintains global industry leadership till date.

XYZ Ltd's mission is to become a global enterprise fulfilling its customers' needs and aspirations for mobility, solidity and sturdiness. The company aims to set benchmarks in technological innovations, style and best in quality to convert its customers into brand advocates. The Company provides an engaging environment for its employees and associates to perform to their true potential. The company aims to continue its focus on value creation and enduring relationships with its partners and shareholders. The company key strategies focus on building a steady and robust product portfolio across categories and explore growth opportunities globally. The company also seeks to continuously improve upon operational efficiency, aggressively expand customer reach, invest in brand-building activities and ensure customer and shareholder delight. The company is rising and is poised to shine on the global arena. Company's new identity is truly reflective of its vision to strengthen focus on mobility and technology and creating

**Table 3**  
Manufacturing Conversion cost determinants.

| Manufacturing Conversion Cost Determinants considered by XYZ Ltd |                                                   |                            |                                                           |
|------------------------------------------------------------------|---------------------------------------------------|----------------------------|-----------------------------------------------------------|
| S.No                                                             | Sections and Manufacturing cost Determinants      | Cost/Vehicles for Fy 15-16 | Descriptions                                              |
| A                                                                | Frame plant (Weld and paint shop)                 | 57.25                      | Total conversion cost consumed in frame plant             |
| 1                                                                | Gas for Oven Heating                              | 17.0                       | Propane gas which is used to heat up the baking Oven      |
| 2                                                                | Paper Masking for Painting                        | 7.18                       | Paper masking is used for cover the area to avoid paint   |
| 3                                                                | Graphics Rejection                                | 6.00                       | This is the out come which can not be used                |
| 4                                                                | Other chemicals used for treatment of paint waste | 4.90                       | Chemicals are used for treatment of paint waste           |
| 5                                                                | Brazing Filler Rod                                | 3.15                       | Brazing filler rod is used for brazing operation          |
| 6                                                                | Sheet Metal Parts Rejection                       | 3.10                       | This is the out come which can not be used                |
| 7                                                                | Paint Removal Chemicals                           | 2.76                       | This chemical is used to remove the flim thickness        |
| 8                                                                | Pretreatment Chemicals                            | 2.40                       | Chemicals are used for pre treatment process              |
| 9                                                                | Mig Wire                                          | 2.11                       | Mig Wire is used in Fuel Tank MIG welding                 |
| 10                                                               | Buffing Abrasive Wheel                            | 2.11                       | Wheel is used to finish the sanding operation             |
| 11                                                               | Oxyacetalene Gas                                  | 1.24                       | DA Gas is used for brazing operation                      |
| 12                                                               | Air filters                                       | 1.16                       | Air filters are used in air supply unit                   |
| 13                                                               | Liquid Argon Gas                                  | 1.05                       | Argon Gas is used as inert gas for shielding the join     |
| 14                                                               | Hand Gloves                                       | 0.83                       | For safety protection                                     |
| 15                                                               | Sanding Disc                                      | 0.65                       | For sanding the welding bead                              |
| 16                                                               | Copper Electrode for Seam Welding                 | 0.63                       | It is used for seam welding operation                     |
| 17                                                               | Sanding Belt                                      | 0.59                       | For sanding the welding bead                              |
| 18                                                               | Rust Preventive Chemical                          | 0.39                       | This chemical is used to protect the components from rust |
| B                                                                | Machine Shops                                     | 37.25                      | All consumable which are used for machining operation     |
| 1                                                                | Tool Cost                                         | 26.2                       | Tools which are used in machining operation               |
| 2                                                                | Consumables                                       | 9.5                        | Tools which are used in machining operation               |
| 3                                                                | Aluminium and Steel Parts Rejection               | 1.55                       | This is the out come which can not be used                |
| C                                                                | Frame Assembly                                    | 5.5                        | All consumable which are used for assembly operation      |
| 1                                                                | Assembly Parts Rejections                         | 2.6                        | Parts rejected while doing assembly                       |
| 2                                                                | Consumables                                       | 2.9                        | Total actual cost is calculated from actual cost as index |
| Total Manufacturing Conversion Cost                              |                                                   | 100                        | Cost index is calculated at 100 scale from actual cost    |

**Table 4**  
Manufacturing cost after improvement\*

| Manufacturing Conversion Cost Reduced by XYZ Ltd |                                             |          |         |        |                                               |
|--------------------------------------------------|---------------------------------------------|----------|---------|--------|-----------------------------------------------|
| S.N                                              | Manufacturing cost Determinants             | Fy 15-16 | Fy17-18 | Saving | Improvement Details                           |
| A                                                | Frame Plant (Weld and Paint Shop)           | 57.25    | 35.67   | 21.58  | Saved US \$2.2 million (INR21.58 /Veh*)       |
| 1                                                | Gas for Oven Heating                        | 17.00    | 10.88   | 6.12   | Change of propane to natural gas              |
| 2                                                | Paper Masking for Painting                  | 7.18     | 1.50    | 5.68   | Masking layout changed                        |
| 3                                                | Graphics Rejection                          | 6.00     | 2.56    | 3.44   | Graphic size optimized                        |
| 4                                                | Chemicals used for treatment of paint waste | 4.90     | 2.50    | 2.40   | Sludge being transferred to cement industries |
| 4                                                | Brazing Fillar Rod                          | 3.15     | 2.28    | 0.87   | Alternate supplier introduced                 |
| 5                                                | Sheet Metal Parts Rejection                 | 3.10     | 2.66    | 0.44   | Process made defect free                      |
| 6                                                | Paint Removal Chemicals                     | 2.76     | 0.76    | 2.00   | Rework improved                               |
| 7                                                | Pre-treatment Chemicals                     | 2.40     | 1.97    | 0.43   | New low temperature chemicals introduced      |
| 8                                                | MiG Wire Dia 0.8mm                          | 2.11     | 1.50    | 0.61   | Wastage reduced                               |
| 9                                                | Buffing Abrasive Wheel                      | 2.11     | 2.00    | 0.11   | Rework reduced                                |
| 10                                               | Oxyacetylene Gas                            | 1.24     | 1.92    | -0.68  | Supplier increased gas price                  |
| 11                                               | Air filters                                 | 1.16     | 1.17    | -0.01  | Alternate supplier introduced                 |
| 12                                               | Liquid Argon Gas                            | 1.05     | 1.02    | 0.03   | wastage reduced                               |
| 13                                               | Hand Gloves                                 | 0.83     | 0.86    | -0.03  | No improvement observed                       |
| 14                                               | Sanding Disc                                | 0.65     | 0.64    | 0.01   | No major improvement observed                 |
| 15                                               | Copper Electrode for Seam Welding           | 0.63     | 0.54    | 0.09   | No major improvement observed                 |
| 16                                               | Sanding Belt                                | 0.59     | 0.56    | 0.03   | No major improvement observed                 |
| 17                                               | Rust Preventive Chemical                    | 0.39     | 0.33    | 0.06   | No major improvement observed                 |
| B                                                | Machine Shops                               | 37.25    | 34.87   | 2.38   | Cost reduced in tool segments                 |
| 1                                                | Tool Cost                                   | 26.20    | 23.65   | 2.55   | High performance tools introduced             |
| 2                                                | Consumables                                 | 9.50     | 9.69    | -0.19  | Cost increased                                |
| 3                                                | Aluminium and Steel Parts Rejection         | 1.55     | 1.53    | 0.02   | Improved through Daily work Management        |
| C                                                | Frame Assembly                              | 5.50     | 5.28    | 0.22   | No major improvement observed                 |
| 1                                                | Assembly Parts Rejections                   | 2.60     | 2.43    | 0.17   | Process made defect free                      |
| 2                                                | Consumables                                 | 2.90     | 2.85    | 0.05   | Improved through Daily work Management        |
| Total Manufacturing Conversion Cost              |                                             | 100.00   | 75.82   | 24.18  | Saved US\$2.27 million (INR24.18 /Vehicle)    |

\*Conversion rate 1US \$ = 70INR.

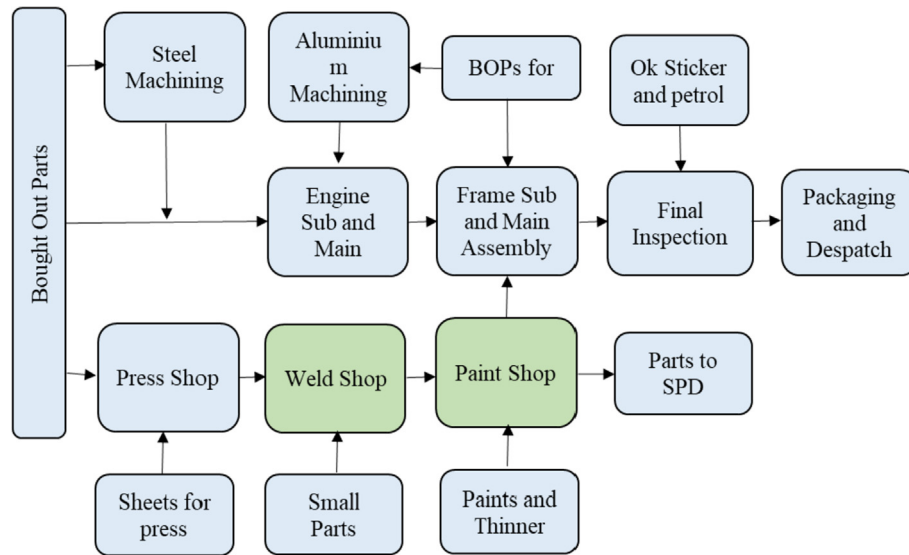


Fig. 3. Manufacturing processes of XYZ Ltd (Source: Discussion with XYZ Ltd).

global footprint. Building and promoting new brand identity will be central to all its initiatives, utilizing every opportunity and leveraging its strong presence across sports, entertainment and ground-level activation.

#### 4.1.1. Description of manufacturing processes

Manufacturing process of XYZ Ltd is shown in Fig. 3. It can be divided broadly into three main sections.

- Frame Manufacturing which consists of welding and Painting
- Machining of components and Engine Assembly

The first stage in Fig. 4 shows the detailed process of frame manufacturing which consists of the Press, Weld and Paint Shop. As per Fig. 4, the fuel tank is formed in press shop and sent to weld shop for further fabrication. Fuel Tank is initially in three parts which are welded with MIG, spot and seam welding. Small parts are welded with spot welding and affixed with brazing operation.

Welded Fuel tank is checked thoroughly for visual defects and leakage testing is done before sending it to paint process. We have considered consumables which are being used in welding process as an input to convert the raw product into finished product. The rejection is recorded through real time data recorder in welding processes and value is registered in SAP and data can be retrieved with any time of intervals. In Painting Process, complete fuel tank is passed through pre-treatment process which consist degreasing-1,2&3 water rinsing-1,2&3, surface conditioning, phosphating and

DM water rinsing, surface drying, painting and paint drying operation and final inspection. As per Fig. 5, finished fuel tanks are sent to frame assembly or Spare Parts Division (SPD) as per requirements.

Input of painting processes are chemicals, hot water, propane gas for heating, paint, thinners. These are being used for pre-treatment, drying oven, painting, baking oven processes. The processes output are complete fuel tank graphics and waste chemicals. The cost of processes comprises cost of gases, chemicals, product waste in terms of graphics, masking and paint removal chemicals.

The machining operations are used to produce the aluminium and steel parts for engine (Fig. 6). The machine shop is divided into two sub sections: For Steel Phase and Aluminium Phase, milling, drilling, reaming and honing operations are carried out to finish the parts as per specifications. All the parts are processed to different checks, inspections and testing. The parts which qualify the quality standards are sent to Engine shop for assembly. Engine is checked and tested with rigorous standards and sent to frame assembly for vehicle assembly.

The firm realizes that the reduction in product scrap cost and consumable cost are the best opportunity to reduce the overall manufacturing conversion cost. Today, manufacturing cost is an important concern for organisations to be more competitive.

#### 4.1.2. Measurement of manufacturing cost elements

Major focus of this study is to analyse conversion cost and explore the actions for its reduction by using quality control tools and monitoring real-time data through digitization techniques. By reducing conversion cost, organizations can save the huge cost in manufacturing for being sustainable in market. Manufacturing conversion cost of case organisation comprises mainly three broad sections. Frame Plant is having eighteen cost elements such as gas for baking oven, graphic waste, brazing filler rod etc. (Table 3). Machining section has three major cost elements i.e. parts waste, consumables and tool cost. Assembly section is having two cost elements i.e. parts rejection and consumables. All the cost elements have been briefly described in Table 3. Authors have used all the cost elements on scale of 100 to keep the case company actual cost data confidential. However, we have shown the actual overall cost saving data in analysis part.

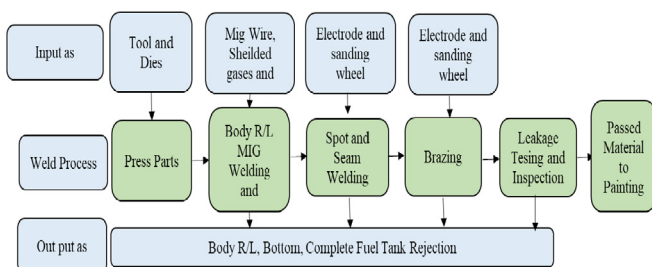


Fig. 4. Welding process and its consumables.

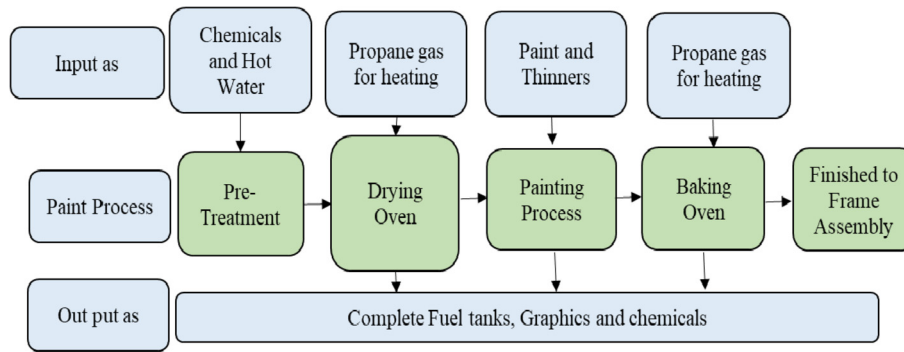


Fig. 5. Painting process and its consumables.

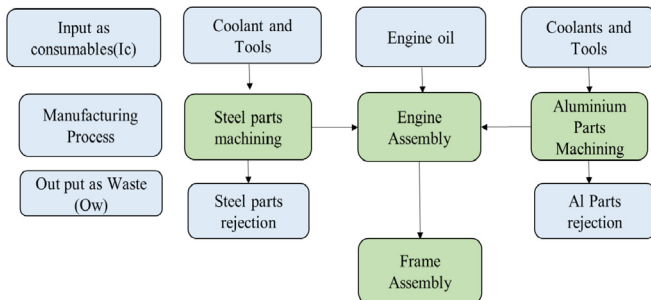


Fig. 6. Machining process and its consumables.

As per data given in Table 3, more than 57.25% of total conversion cost is consumed in frame plant i.e. welding and painting operations and second highest consumption is having machine shop i.e. 37.25%. The frame assembly contribute least cost to convert finished product i.e. 5.5%. This paper has used the Quality Control (QC) tools and digitization technology to get real time data recording as discussed in following sections.

#### 4.2. Analysis of real time data

Presently, many organisations are emphasizing in upgrading their existing manufacturing processes through automation. Singh et al. (2019) have observed that IT enabled processes help in making organisations sustainable and competitive. The fourth industrial revolution called as industry 4.0 focuses on automating processes which is giving real time information data through the use of cyber-physical systems (CPS) (Kagermann, 2015). This process is integration of digital, digitalization and Digital transformation. Pfohl et al. (2017) explained digitalization of manufacturing process or product as a key enabler of Industry 4.0. There are steep increase of research papers talking about terms as digitization, digitalization, and digital transformation in recent past. Buer et al. (2018) tried to distinguish these three terms as follows:

**Digitization:** Conversion of analogue format into a digital format.

**Digitalization:** Integration of digital data into technology to automate and optimize processes.

**Digital transformation:** Creating new business opportunities through the use of digital data and technology.

This study proposes to measure and record specific processes to

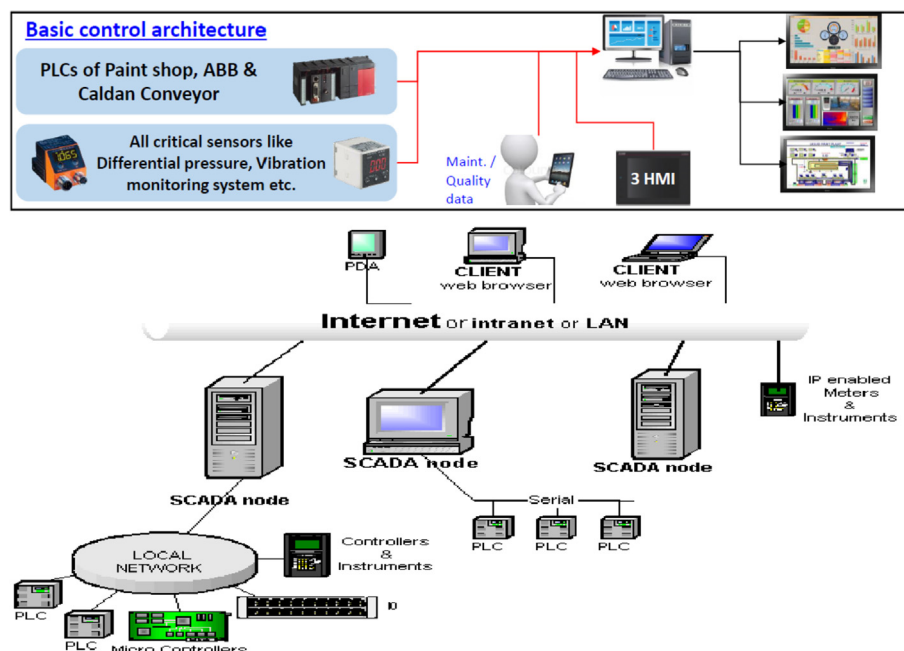


Fig. 7. Realtime data recording system.

get real time data which can be used in DMAIC process to get authenticity in data recording process. Real time data collection for quick analysis has become a big challenge for some of organisations (Parviainen et al., 2017). In Industry 4.0 environment, many manufacturing processes are getting automated and digitized (Möller, 2016). Real time data collection through digitisation of operations has become most important for effective operations (Kolberg and Zühlke, 2015). The supervisory control and data acquisition (SCADA) and SAP a recording system, are being used by case company for real time data recording and storing them into cloud (Fig. 7). All the gases, chemicals are being recorded in system on real time basis and rest of other parameters like electricity consumptions and all other consumable are being recorded in these two Systems. We can retrieve the data at any time period for detailed cost analysis.

The company has integrated digitization through existing Human Machine interface (HMI) into their system to get real time data of different cost elements. All the elements are analysed on real time basis and correction done on parameters which are deviated from standards. All the data are being stored in cloud as big data (Qi and Tao, 2018) for further analysis for forecasting and budgeting purpose.

The company is always using data to support strategic decision making. The data is being collected on real time basis with Mitsubishi human machine interface (HMI) on sporadic, periodic, or continuous basis. The data appear in a physical or digital format, and can be collected with or without human intervention in most of cases. Data may be observed in different desired ways e.g. through measurement, one-line inspection of products, counting, comparing and reading. The collected data is displayed on big screen and analyst give information about situation of processes and the deviations of the key variables. Auto correction is done on the deviated process or sometimes manual intervention is required on the basis of business requirement.

#### 4.3. Improvements and results discussion

Pareto Analysis is used to prioritize the determinants of manufacturing conversion cost. As observed from data given in Table 3, more than 52% of total conversion cost is contributed by frame plant i.e. welding and painting operations and second

highest contributor is machine shop. The frame assembly is having least cost contribution to conversion cost. Pareto chart for different cost elements and respective contribution is plotted in Fig. 8.

From Pareto chart (Fig. 8), it is observed that 80% cost contributors are tool cost, Gas for baking oven, consumables used for machine shop, paper masking, graphic rejection, brazing filler rod, and sheet metal parts rejection. Therefore, firm has focused on these major contributors of conversion cost to reduce overall manufacturing cost. It may also help in elimination of waste and in making manufacturing processes more sustainable (Doyle et al., 2019).

#### 4.4. Tool cost

All the probable causes of high tool cost are explored in the form of cause and effect diagram as shown in Fig. 8. Different elements of tool cost are mentioned in Fig. 9. The cutting tool consists of all tools which are used for machining of steel and aluminium parts. Die & fixtures parts, assembly tightening guns are also considered in this category. The early wearing of the tools and lesser life of tools are main contributor of higher cost. The cutting tools are also known to affect size of components, surface quality and production time results in higher tool cost and defective parts rejection.

According to Ghani et al. (2011), the real time data recording system can be installed to detect and analyse real time signals. The signals will detect the deflection or vibration of the tool holder from the undue cutting force. The same corresponding data estimation of tool wear is displayed on the computer screen. New data statistical analysis can be used to identify the changes in signals from the sensors.

#### 4.5. Gas for heating the oven

All the probable causes of high gas consumption are given in form of Cause and effect diagram as shown in Fig. 10. The propane gas is used for heating up the oven to drying the painted components. It costs INR 17 per vehicle, which is most significant contributor to conversion cost. All the probable causes of high gas consumptions are analysed. There are two probable causes. First, the equipments are not having real time data monitoring system and second, management has not explored the availability of

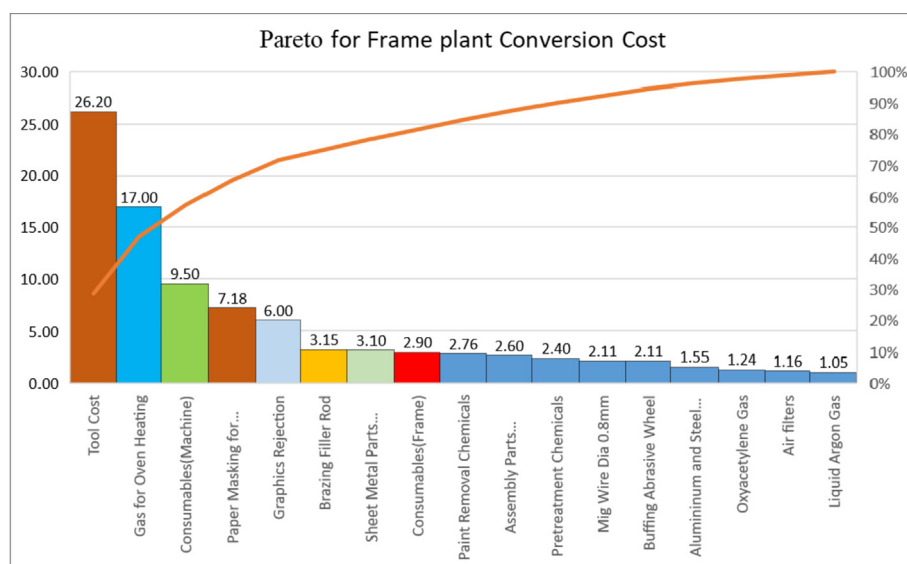


Fig. 8. Pareto analysis for manufacturing conversion cost.

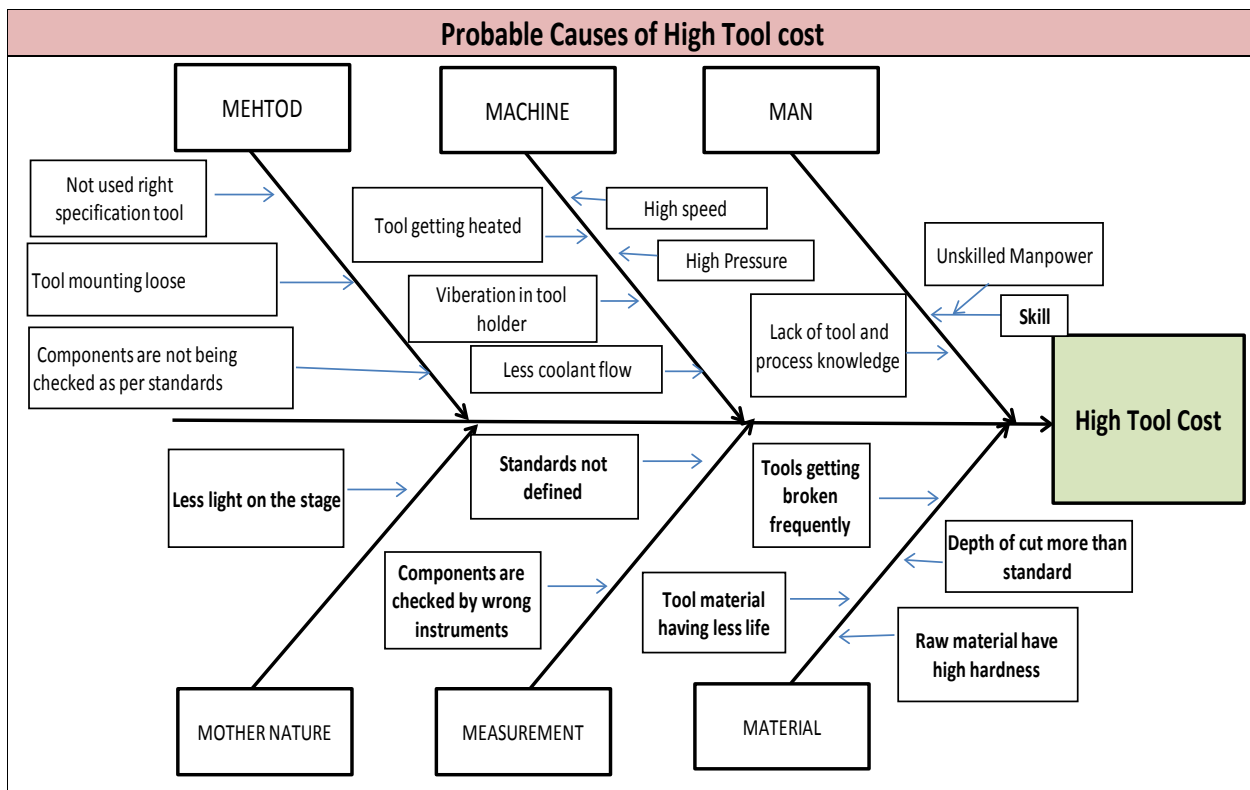


Fig. 9. Cause and Effect diagram of high tool cost.

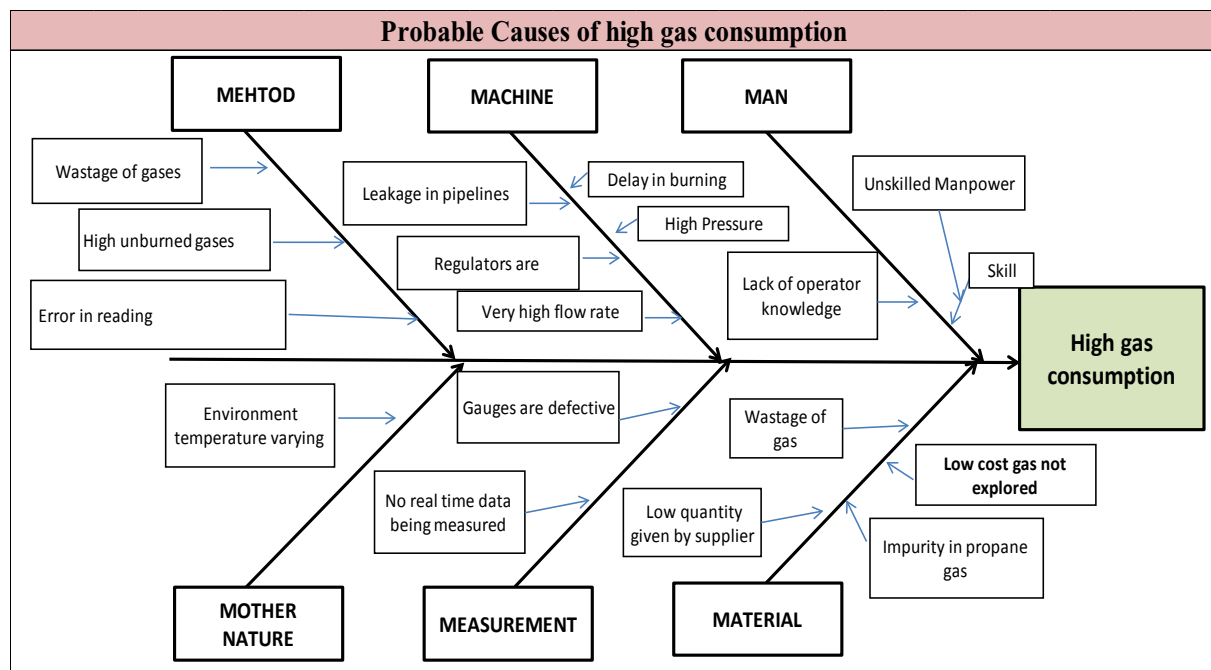


Fig. 10. Cause and effect diagram of high gas consumption.

alternate low-cost gases in the market. The other high cost items are also analysed in the same way.

XYZ Ltd through policy deployment (Posteucă and Zapciu, 2015; Posteucă and Sakamoto, 2017) and daily work management activities is focusing on manufacturing conversion cost and thus

improving the existing process. The following are the activities carried out by this company to control this cost.

- Daily manufacturing report and section level manufacturing conversion cost data analysis and action plan for next day.

- Consumables data tracking, stage and operation wise and root cause analysis for any variation.
- Stage wise rejection data collection and root cause analysis of variations and making action plan for next day or shift.
- Kaizens and high-level projects for breakthrough improvement to eliminate the processes wastes and consumables cost reduction.

#### 4.6. Controls for process sustainment

On the basis of analysis of data of different processes, XYZ Ltd has taken counter measures for all root causes of high conversion cost. High performance tools are introduced to enhance the tool life as it was one of the biggest cost contributors. The strategic decision was taken by management for technological change of propane to natural gas. Paper masking is used to protect the surface from painting processes and size is optimized by changing the layout of masking. It has high energy consumption in heating the chemicals in paint shop. The new chemicals introduced can work on low temperature with high performance. Company is working on process improvement through technological innovation and getting competitive advantage in context to cost saving. The case company has started using natural gas in place of propane gas which is impacting on cost saving of INR7 per vehicle. The Improvement on consumables is visible and poor-quality products are also in reducing trend. The cost due to sheet metal parts rejection is reduced from INR 3.10 to 2.66 per vehicle and due to graphic rejection, cost is reduced from INR 6.00 to INR 2.56 per vehicle. According to Prashar (2018), the process can be made further lean by reducing the cycle time of manufacturing processes through minimising the product rejection. Paper masking was having forth highest cost impact of INR 7.18 per vehicle on manufacturing conversion cost. This cost was reduced from INR 7.18 to INR 1.50 per vehicle by optimizing the masking size through layout modification of the paper template and it has resulted huge cost saving of INR 6.05 per vehicle. The graphic rejection was major concern of product waste and giving impact on cost INR 6.0 per vehicle. It was reduced to INR 2.56 by improving worker skills and optimization of paper masking size. It has resulted saving of INR 3.75 per vehicle. The brazing filler material rod was costing INR 3.15 per vehicle and it was reduced to INR 2.28 by introducing the alternate supplier. This gave the saving of INR 0.87 per vehicle.

The case company has installed an online tool wear measurement and monitoring system using a low-cost sensor to monitor real time data. The system is also able to detect and analyse real time signals which are relating to the deflection or vibration of the tool holder from the undue cutting force, and the same corresponding data estimation of tool wear is displayed on the computer screen. New data statistical analysis is used to identify the changes in signals from the sensors. On the basis of this feedback, the required correction is done and tool life is enhanced. The company also introduced new tools which are giving high tools life and company is able to reduced cost by INR 2.55 per vehicle.

#### 5. Key findings

The critical examination of manufacturing conversion cost in an original equipment manufacturer (OEM) is carried out through established systematic process in this study. The manufacturing conversion cost determinants are analysed through Pareto chart, cause and effect diagram. The gas consumption cost and tool cost were found to be the most contributing factors. To reduce conversion cost, major initiatives taken by this organisation are change of Propene to natural gas for oven heating, change of masking layout,

graphic size optimisation, sludge being transferred to cement industry, introduction of new low temperature chemical. These initiatives have helped in reducing pollution due to chemicals, wastage reduction and conversion cost reduction. Due to different initiatives, this organisation is saving INR 24.18 per vehicle in conversion cost. Some of the key findings of this study can be summarised as follows.

- Total annual saving of the company is USD 2.2 million at the rate of INR 24.18 per vehicle. The strategic decision was taken by management for technological change of propane to natural gas. It resulted in saving of INR 6.12 per vehicle.
- The change in pre-treatment chemicals has also resulted in saving of INR 0.55 per vehicle apart from reduction of chemical pollution.
- Modification in graphics design has resulted savings of INR 3.44 per vehicle.
- Modification in paint stripping chemical and other chemical have resulted total savings of INR 4.40 per vehicle.

Apart from above major improvements, minor improvements are also evident in machine shop and frame assembly of case organisation. Machining processes can be further improved by application of statistical techniques for solving issue of major rejection and rework because of process variation.

#### 6. Conclusion, managerial implications and future scope

The automobile manufacturers are currently facing a big pressure to reduce the overall manufacturing conversion cost to be more competitive in the global market. The purpose of this study is to develop the framework to identify and analyse elements of manufacturing conversion cost. In this context, eighteen cost determinants of manufacturing conversion cost are explored and analysed by using tools like Pareto chart, cause and effect diagram and digitisation of operations.

The manufacturing process is broadly divided into three sub processes. Frame plant consists of weld shop and paint shop. It is having more than 50% of total conversion cost. It is observed that cost can be reduced through technological innovations or small continuous changes. Some of the technological initiatives taken by this organisation are replacing propane gas with natural gas, reduction in graphics rejection by changing the product design and modification in pre-treatment chemical formulation. Some of the areas like tool cost reductions are still having scope of improvements. It is observed that by taking these initiatives, organisation has saved around 2.2 million USD (@INR 24.18 per vehicle) in a year. As the volume of production will increase, this saving may further increase in exponential manner. Such kind of savings would make organisations sustainable in hyper competitive environment.

Laureijs et al. (2017) have observed in their research that low-cost, highly customizable production process for complex parts through new technologies like Additive manufacturing (AM) is being made possible in many industries. Researchers have also observed that AM is as main restrains in context to high process costs (Bonnín-Roca et al., 2017; Scott and Harrison, 2015; Costabile et al., 2017). But no such study has been done to reduce the conversion cost without much investment in complete manufacturing system. The findings of this research would motivate other organisations to change their manufacturing strategy orientation for cost reduction. Although cost saving per vehicle may be very less but overall savings for mass production systems like automobile sector may be huge. Findings would be useful for other manufacturing sectors also as conversion cost is still not the priority in most of the manufacturing sectors. Researchers would also

be motivated to consider conversion cost while exploring operations strategy for future research. Initiatives taken by organisation have helped not only in reducing cost but also in making manufacturing processes more sustainable. Major limitation of this study is that, it could quantify only cost benefits. Sustainability measures such as reduction in chemical waste, gas pollution, and wastage of material could not be quantified. Therefore, as a future scope, study may try to explore new initiatives for making processes greener apart from cost reduction.

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**Mr. Veer Shivajee** is research scholar at Indian Institute of Foreign Trade (IIFT), Delhi, India. He has around 25 years experience in Indian automobile sector. His areas of interest are Industry 4.0, Quality Management and Productivity improvement. Email: [veersshivajee@gmail.com](mailto:veersshivajee@gmail.com)

**Dr. Rajesh Kr. Singh** is a Professor in Operations Management area at Management Development Institute, Gurgaon, India. His areas of interest include Supply Chain Management, Industry 4.0, Circular Economy and Logistic Management. He has published around 170 research papers in reputed international/national journals and conferences. His papers have appeared in journals such as International Journal of Production Research, Annals of Operations Research, Resources, Conservation and Recycling, Journal of Cleaner Production, Production Planning and Control, Journal of Industrial and Production Engg, Industrial management and Data Systems, Singapore Management Review, International Journal of Productivity and Performance Management, Benchmarking: An International Journal, Journal of Modelling in Management, Competitiveness Review, Global Journal of Flexible Systems and Management, Journal of Advances in Management Research, International Journals of Productivity and Quality Management, International Journal of Services and Operations Management, Management Research Review, IIMB Management Review etc. Email: [rksdce@yahoo.com](mailto:rksdce@yahoo.com)

**Dr. Sanjay Rastogi** is Professor in Operations area at Indian Institute of Foreign Trade (IIFT), Delhi, India. His areas of research interest are Quantitative Techniques, Business Research Methods, Econometrics. He has published many research papers in reputed international conferences and journals. He has got more than 15 years teaching and research experience. Email: [srastogi@iift.edu](mailto:srastogi@iift.edu)