COST REDUCTION THROUGH LEAN APPROACH IN NATURAL GAS DEHYDRATION PROCESS: A CASE STUDY

Mustafa Shaafee Saleheen Towfique

Department of Industrial and Production Engineering

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

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By

Mustafa Shaafee Saleheen Towfique

This thesis submitted to the Department of Industrial and Production Engineering, Bangladesh University of Engineering and Technology in partial fulfillment of the requirements for the degree of Master of Engineering in Advanced Engineering Management

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CERTIFICATION OF APPROVAL

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BOARD OF EXAMINERS

Prianka

1 Prianka Binte Zaman — Chairman (Supervisor)
Assistant Professor
Department of IPE, BUET, Dhaka

Syl.

2 Dr. Syed Mithun Ali — Member
Associate Professor
Department of IPE, BUET, Dhaka

Shuva Ghosh

3 Dr. Shuva Ghosh — Member
Assistant Professor
Department of IPE, BUET, Dhaka

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It is hereby declared that this thesis or any part of this has not been submitted elsewhere for the award of any degree or diploma.

March 12, 2019

(Mustafa Shaafee Saleheen Towfique)

Signature of the Candidate

Nomenclature

AFB	: Accrued Financial Benefit
MMSCF	: Million standard cubic feet
MMSCFD	: Million standard cubic feet per day
TEG	: Tri-Ethylene Glycol
GPM	: Gallon Per Minute
DMAIC	: Define, Measure, Analyze, Improve & Control
BOAT	: Barrier, Opportunity, Action & Threat
COPQ	: Cost of Poor Quality
PICK	: Possible, Implement, Challenge and Kill
OPM	: Operating Manual
OPS	: Operations personnel
OPEX	: Operation Expense
BPD	: Barrel per Day
MSDS	: Material Safety data sheet
SOP	: Standard Operating Procedure
SOW	: Scope of Work
AZS	: Automatic Zero Set
HIS	: Human Interface System
EIS	: Executive Improvement Summary
IOC	: International Oil Company
MOC	: Management of Change
OEE	: Overall Equipment Effectiveness
VSM	: Value Stream Map
ANOVA	: Analysis of Variance
MSA	: Measurement System Analysis
TQM	: Total Quality Management
EOQ	: Economic Order Quantity
PFMEA	: Process Failure Mode Effective Analysis
DFMEA	: Design Failure Mode Effective Analysis

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ABSTRACT

Lean approaches for cost reduction have been vastly used in batch processing like automobile manufacturing industries (Toyota, Ford), in line manufacturing (Garments, pharmaceuticals industries), discrete manufacturing (aircraft industry) and medical technologies (Oncology). However, this approach has not found to be used in continuous production process like upstream natural gas processing industry. For this research, a total number of 03 (three) cases were modeled, incorporating change in a natural gas plant's Charcoal filter consumption, varying absorbent (Tri-ethylene glycol) flow rate and tuning Re-boiler still column temperature. In this study, a lean six sigma approach has been applied in country's largest natural gas plant's gas dehydration process by using different tools like DMAIC model (Define, Measure, Analyze, Improve & Control), BOAT model (Barrier, Opportunity, Action & Threat), COPQ (Cost of Poor Quality) calculation, PICK chart (Possible, Implement, Challenge and Kill). Applying these tools, absorbent (TEG) loss and carbon filter replacement frequency has been reduced in atmospheric condition of Bangladesh and operational cost reduced to AFB $3,63,365 approximately. From this study; other natural gas plants of Bangladesh as well as of Asia, Africa and Arab basins can gain an understanding of lean six sigma process implementation and practices of sustainable cost reduction.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Lean Six Sigma is the structured application of both quality and statistical tools with the purpose of gaining process knowledge to make the output metrics safer, better, faster, and lower cost. This is the methodology to realize tangible business value by systematically improving existing processes.

This study is focused towards the natural gas production and processing plants of Bangladesh as well as Asia, Arab and African basins where gas dehydration and absorbent regeneration is the main challenge.

1.2 Background of the study

The oil & gas industry is full of economic booms and busts. Starting from 2015, the industry falls in a downturn. As a result, the price of crude oil has dropped significantly. Earnings went down for the companies that have made high profits over the past five years. These companies have responded by decommissioning half their overall rigs and cutting investments in exploration and production.

The absolute peak occurred in June 2008 with the highest inflation adjusted monthly average crude oil price of $141.32/ barrel. The Average price in U.S. dollars per barrel crude oil was in 2012, 2013, 2014, 2015 and 2016 are respectively $109.45, $105.87, $96.29, $49.29 and $40.68. On 18 January 2016 it was $27.67/ barrel the lowest since 2003 [1].

The cause of the downturn is the declining price of a barrel of oil, which is due to the strong U.S. dollar, OPEC, oversupply, declining demand and the Iran nuclear deal. Prices have been cut in half in less than a year, reaching lows that people have not seen since the last global recession. Prices have recovered periodically in 2015, but many oil executives believe it will be years before oil returns to $100 per barrel [2].

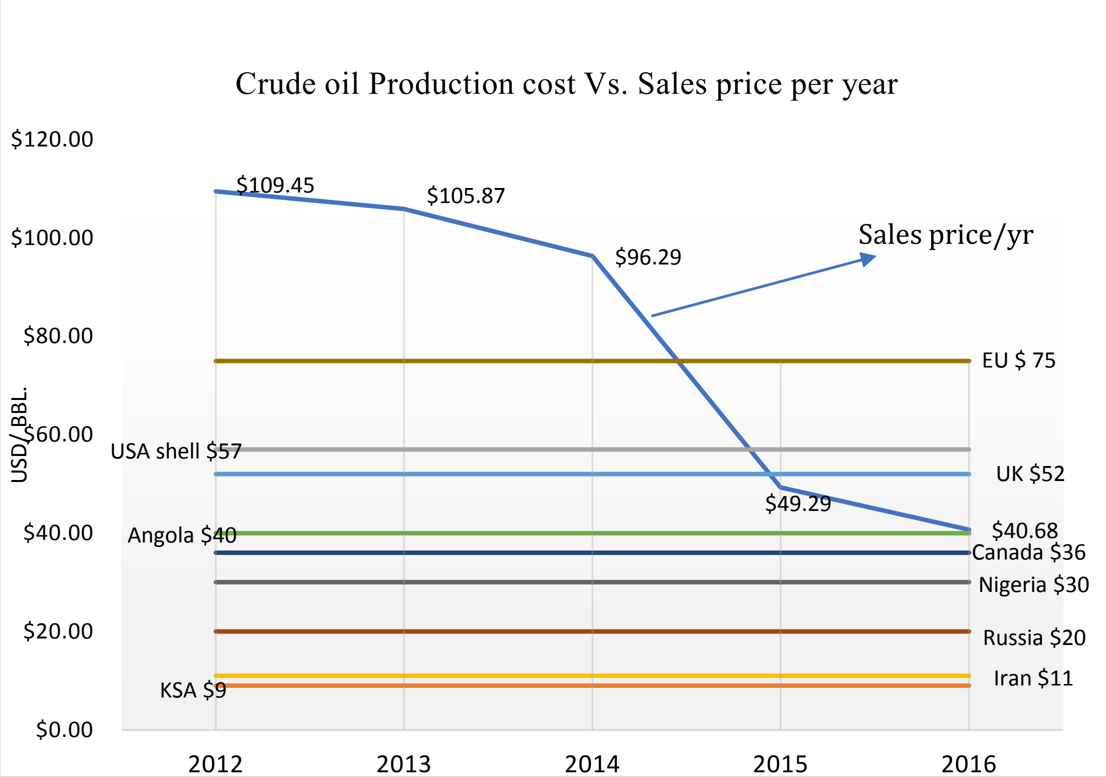

Fig 1.1: Crude oil production cost Vs. Sales price per year

The Strong US Dollar

The strong U.S. dollar has been the main driver for the price decline of crude oil over the last few years. In fact, the dollar is at a 12-year high against the euro, leading to appreciations in the U.S. dollar index and a reduction in oil prices. This puts the market under a lot of pressure, because when the value of the dollar is strong, the value of commodities falls. Global commodity prices are usually in dollars and fall when the U.S. dollar is strong. For example, the surge in the dollar in the second half of 2014 caused a sharp fall in the leading commodity indexes.

Organization of the Petroleum Exporting Countries (OPEC)

Another leading factor in the sharp price drop of crude oil is that OPEC, a cartel of oil producers, is unwilling to stabilize the oil markets. Prices of OPEC's benchmark crude oil have fallen 50% since the organization decided against cutting production at a 2014 meeting in Vienna.

Of the participating countries in OPEC, Iran, Venezuela and Algeria have wanted to cut production to firm up prices. Saudi Arabia, the United Arab Emirates and other

Gulf allies refuse to do so. Iraq sits alone as the only OPEC country to not only maintain supply but actually increase it. If OPEC does not cut production, the result is a further oversupply of oil, placing downward pressure on crude oil prices for the long term.

Oversupply of Crude Oil

Crude futures declined in late September 2015 given that the global oversupply is increasing oil stockpiles. Total oil production by year-end 2015 is expected to rise to over 9.35 million barrels per day, higher than the 9.3 million barrels per day forecasted in February 2015. This shows that not only is the market oversupplied, but supply is actually increasing.

Unrelated to futures, oil inventories have risen more than expected. The Energy Information Administration (EIA) reported on Sept. 30, 2015, that U.S. commercial crude oil inventories rose by 4.5 million barrels from the previous week. At almost 500 million barrels, U.S. crude oil inventories are at the highest level in at least the last 80 years, causing a decline in prices.

Declining Demand

While supply is increasing, demand for crude oil is decreasing. The economies of Europe and developing countries are weakening, and at the same time, vehicles are becoming more efficient, which has caused the demand for fuel to lag. China's devaluation of its currency suggests its economy may be worse off than expected. With China being the world's largest oil importer, this is a huge hit to global demand.

Iran Nuclear Deal

The Iran nuclear deal is a preliminary framework agreement reached between Iran and a group of world powers. The framework seeks to redesign, convert and reduce Iran's nuclear facilities. The U.S. nuclear deal with Iran allows more Iranian oil exports. The deal removes Western sanctions against Iran, and investors fear it will add to the world's oversupply of oil. Markets have already reacted to this news by decreasing the price of crude oil.

Under this circumstances, all small and large oil and gas companies i.e. Exxon Mobil, ConocoPhillips Corporation, Sinopec, Total S.A., British Petroleum, Royal Dutch Shell, Weatherford, Schlumberger, China National Petroleum corporation, Gazprom, Lukoil had to cut a large numbers of employees and initiate to establish cost reduction culture so that in father crude oil price drop they can survive with the vary basic expenses.

This phenomenon also affected world's oil and gas job market as the stated giant companies became bound to cut large number of employees to tackle down turn. Large number of small IOC companies became bankrupted in this situation. IOC companies also run their business in Bangladesh's energy sector. On this ground, any cost reduction initiative in the gas plants of Bangladesh will be of high significance.

1.3 Rationale of the study

Due to oil market downturn most of IOCs facing challenges to their existence. Hence, any sustainable cost reduction attempt is very convivial for IOCs now a days. Elimination of waste, improving operations, increasing productivity, cheaper materials and improved standards of quality are the best ways of reducing cost. Lean six sigma, Just in Time approach, Standard costing, Target costing, Total Quality Management (TQM), Economic Order Quantity, Market research, Benchmarking, Inventory Management and Control, Management Audits, Business Process-re-engineering, Activity Based Management (ABM) and Life Cycle Costing are the tools for cost reduction. But in Oil & Gas industry, natural gas dehydration process deals only with improving operations and elimination of wastes which best suited to lean approaches. Furthermore; purpose of ensuring sustainability of cost reduction motivates towards lean six sigma methodology.

Lean approaches for cost reduction have been massively practiced in batch processing like automobile manufacturing industries (Toyota, Ford), in line manufacturing (Garments, pharmaceuticals industries) [5], discrete manufacturing (aircraft industry) and medical technologies (Oncology). But studies are hardly found which dealt with this approach in continuous production process like upstream natural gas processing industry. Lean approach with the integration of six sigma methodology through

DMAIC model has been applied in natural gas processing industry aiming towards establishing sustainable cost reduction in this study.

1.4 Objectives of the study

The objectives of this thesis work are:

- Application of Lean approach with integration of six sigma methodology through DMAIC model in natural gas processing industry.
- Identification of critical section of absorbent (Tri-ethylene glycol) regeneration flow in natural gas dehydration process where major TEG losses occur and charcoal filter lifetime degrades by analyzing process control narrative and historical data.
- Reduction in natural gas plant operational cost through reducing absorbent (Tri-ethylene glycol) loss and carbon filter consumption frequency in Glycol regeneration stream of gas dehydration process.

The outcome of this study provided a holistic pathway on potential opportunities for other natural gas plants of Bangladesh as well as of Asia, Africa and Arab basins which can gain an understanding of lean six sigma process implementation and practices of sustainable cost reduction in natural gas dehydration.

1.5 Outline of Methodology

The project methodology is outlined below:

- Study all major sections of natural gas processing plant including gas dehydration and absorbent (TEG) regeneration process in detail.
- Collecting operational data on gas production rate, absorbent (TEG) consumption, Charcoal filters consumption, absorbent (TEG) circulation rate, re-boiler temperature, dew point of processed gas, maintenance and production downtime.
- Apply Lean six sigma approach by using DMAIC model as follows:
- **Define** problem statement including the magnitude of the problem using “As is-To Be” Process map.
- **Measure** the current state of the problem by using pie chart and bar chart.

- **Analyze** whether the taken steps work or not by using Correlation analysis in PI software (A suite of software products that are used for data collection, historicizing, analyzing, delivering, and visualizing), cost-data analysis and BOAT model.
- Calculation of COPQ (Cost of Poor Quality) to identify the **improvement** by applied lean six sigma approach.
- Develop **Control** plan to sustain the cost reduction using PICK chart.

1.6 Organization of the Thesis

For a better understanding of this research work, this thesis report is organized in several chapters.

Chapter 1, ***Introduction*** contains some general introduction, specific objectives and methodology of this study and information regarding organization of chapters of this report.

Chapter 2, ***Literature Review*** provides brief descriptions on some of the previous works related to this study. This chapter also contains relevant information and general information required to conduct the study.

Chapter 3, ***Theoretical Framework*** provides necessary theoretical background required to understand criteria of using DMAIC tool. This chapter also describes other terminologies, tools, aids and methods which have been used to implement lean six sigma process.

Chapter 4, ***Case Study*** narrates the organizational profile of the company where the case study was implemented for better understanding the rationale of the study. It also contains the statement of the problem as well as the challenge to resolve.

Chapter 5, ***Data collection***, ***Implementation and Results Analysis*** deal with research methodology for data collection and steps required to perform the study. It also describes findings and analysis from case study in order to identify after effect of lean approach to the customer end.

Chapter 6, ***Conclusions and Recommendations*** contain some conclusions and recommendations, which are made based on the project outcome and results.

CHAPTER 2

LITERATURE REVIEW

2.1 Cost reduction

Today the world has become a global village; business competition crosses the national border. Every business arena is facing global competition. Survival becomes increasingly difficult and it becomes more and more critical to find new ways to grow or sustain business. The Oil and gas industry is one of the industries who face the most challenging business competitions.

Cost reduction is the process used by companies to reduce their costs and increase their profits. Depending on a company's services or product, the strategies can vary. Every decision in the product development production process affects cost. Cost becomes more important when competition increases and price becomes a differentiator in the market.

Lean manufacturing process is an extensive way to reduce waste from any manufacturing industry with the help of various types of tools [3].

2.2 Cost reduction strategies

Market globalization era enhances the competitive economic situations and demands supply of required products in less cost. In striving to remain competitive, the concepts of sustainable cost reduction have been extremely employed to the production system. Fundamentally five rudimentary steps are essential to reduce cost. They are as follows [4]:

- Elimination of waste
- Improving operations.
- Increasing Productivity.
- Cheaper materials.
- Improved Standards of Quality

2.3 Tools for cost reduction

There are a number of established tools for cost reduction which can be used to satisfy the five rudimentary steps of cost reduction stated above.

2.3.1 Lean six sigma

Lean Six Sigma is a method that relies on a collaborative team effort to improve performance by systematically removing waste and reducing variation. It combines lean manufacturing/lean enterprise and Six Sigma to eliminate the eight kinds of waste (muda): Defects, Over-Production, Waiting, Non-Utilized Talent, Transportation, Inventory, Motion, Extra-Processing

Lean six sigma not only reduces process defects and waste, but also provides a framework for overall organizational culture change [5].

2.3.2 Just in Time approach

Just-in-Time is said to be a model system of the manufacturing industry that was formulated by Mr. Taiichi Ohno as the Toyota Production System. Behind the creation of JIT was the issue of whether the Japanese auto industry could survive after the war.

Just-in-time (JIT) manufacturing, also known as just-in-time production or the Toyota Production System (TPS), is a methodology aimed primarily at reducing times within production system as well as response times from suppliers and to customers. Its origin and development were in Japan, largely in the 1960s and 1970s and particularly at Toyota [6].

A case-study summary from Daman Products in 1999 lists the following benefits: reduced cycle times 97%, setup times 50%, lead times from 4 to 8 weeks to 5 to 10 days, flow distance 90% – achieved via four focused (cellular) factories, pull scheduling, kanban, visual management, and employee empowerment [7].

2.3.3 Standard costing

A standard costing system is a tool for managing and controlling costs, planning budgets and evaluating cost management performance.
A standard costing system involves estimating the required costs of a production process. But before the start of the accounting period, the standards need to be determined. The regarding amount and cost of direct materials, the amount and pay rate of direct labor required for the production process need also to be set. In addition, these standards are used to plan a budget for the production process.

At the end of the accounting period, the actual amounts and costs of direct material are used. Then the actual amounts and pay rates of direct labor is utilized to compare it to the previously set standards. When the actual costs are compared to the standard costs and variances between them are examined, it allows managers to look for ways to improve cost control, cost management, and operational efficiency.

There are both advantages and disadvantages to using a standard costing system. The primary advantages to using a standard costing system are that it can be used for product costing, for controlling costs, and for decision-making purposes.

Whereas the disadvantages include that implementing a standard costing system can be time consuming, labor intensive, and expensive. If the cost structure of the production process changes, then update the standards [8].

2.3.4 Target costing

Target costing is an approach to determine a product’s life-cycle cost which should be sufficient to develop specified functionality and quality, while ensuring its desired profit. It involves setting a target cost by subtracting a desired profit margin from a competitive market price. A target cost is the maximum amount of cost that can be incurred on a product, however, the firm can still earn the required profit margin from that product at a particular selling price. Target costing decomposes the target cost from product level to component level. Through this decomposition, target costing spreads the competitive pressure faced by the company to product’s designers and suppliers. Target costing consists of cost planning in the design phase of production as well as cost control throughout the resulting product life cycle. The cardinal rule of target costing is to never exceed the target cost. However, the focus of target costing is not to minimize costs, but to achieve a desired level of cost reduction determined by the target costing process.

Target costing is defined as "a disciplined process for determining and achieving a full-stream cost at which a proposed product with specified functionality, performance, and quality must be produced in order to generate the desired profitability at the product's anticipated selling price over a specified period of time in the future" [9]. This definition encompasses the principal concepts: products should be based on an accurate assessment of the wants and needs of customers in different market segments, and cost targets should be what result after a sustainable profit margin is subtracted from what customers are willing to pay at the time of product introduction and afterwards.

The fundamental objective of target costing is to manage the business to be profitable in a highly competitive marketplace. In effect, target costing is a proactive cost planning, cost management, and cost reduction practice whereby costs are planned and managed out of a product and business early in the design and development cycle, rather than during the later stages of product development and production [10].

2.3.5 Total Quality Management (TQM)

Total quality management (TQM) consists of organization-wide efforts to install and make permanent climate where employees continuously improve their ability to provide on demand products and services that customers will find of particular value. "Total" emphasizes that departments in addition to production (for example sales and marketing, accounting and finance, engineering and design) are obligated to improve their operations; "management" emphasizes that executives are obligated to actively manage quality through funding, training, staffing, and goal setting. While there is no widely agreed-upon approach, TQM efforts typically draw heavily on the previously developed tools and techniques of quality control. TQM enjoyed widespread attention during the late 1980s and early 1990s before being overshadowed by ISO 9000, Lean manufacturing, and Six Sigma [11].

2.3.6 Economic Order Quantity

Economic order quantity (EOQ) is the order quantity that minimizes the total holding costs and ordering costs. EOQ applies only when demand for a product is constant over the year and each new order is delivered in full when inventory reaches zero. There is a fixed cost for each order placed, regardless of the number of units ordered. There is also a cost for each unit held in storage, commonly known as holding cost, sometimes expressed as a percentage of the purchase cost of the item.

2.3.7 Benchmarking

Benchmarking is the practice of comparing business processes and performance metrics to industry bests and best practices from other companies. Dimensions typically measured are quality, time and cost. Benchmarking is used to measure performance using a specific indicator (cost per unit of measure, productivity per unit of measure, cycle time of x per unit of measure or defects per unit of measure) resulting in a metric of performance that is then compared to others [12].

It is also referred to as "best practice benchmarking" or "process benchmarking". This process is used in management which particularly shows strategic management, in which organizations evaluate various aspects of their processes in relation to best practice companies' processes. Usually the purposes of comparison are defined within a defined peer group. This then allows organizations to develop plans on how to make improvements or adapt specific best practices, usually with the aim of increasing some aspect of performance. Benchmarking may be a one-off event but is often treated as a continuous process in which organizations continually seek to improve their practices.

2.3.8 Inventory Management and Control

As a significant contributor to efficiency and cost savings, inventory management plays a pivotal role in giving a company a competitive advantage.

Inventory management refers to the process of looking after non-capitalized assets. It is a key process in supply chain management and monitors the movement of goods from manufacturer to warehouse, and from warehouse to the end customer. Critical to this process is the keeping of a detailed record of each and every product. Inventory control seeks to strike the delicate balance between minimizing inventory costs and the ability to satisfy customer demands in a timely manner. Occasionally, inventory control and inventory management can be used interchangeably.

Inventory management occurs throughout the supply chain management process. An efficient system will ensure that records are kept every step of the way and that management is alerted to any problems early in the process, making them easier to solve. The aim is always to shorten the order fulfilment time without incurring additional costs.

Benefits of Inventory management and control are continuous supply of raw material and finished goods for consistent production, reduction of inventory associated costs including theft, obsolescence, wastage etc. and maximum customer satisfaction with timely and effective distribution.

2.3.9 Management Audits

Management audit is an investigation of business from the highest level downward in order to ascertain whether sound management prevails throughout, thus facilitating the most effective relationship with outside world and smooth running of internal organization.

Management auditing is a method to evaluate the efficiency of management at all levels throughout the organization, or more specifically, it comprises the investigation of a business by an independent body from the highest executive level downwards, in order to ascertain whether sound management prevails through and to report as to its efficiency or otherwise with recommendations to ensure its effectiveness where such is not the case.

Scopes of management audits are much wider than financial audit because management audit evaluates not only financial audit but also other aspects of the business. It is the method of evaluating the total efficiency of the management from the top level to the lowest level. Therefore, the main scopes of management audit are 1. Evaluating the Efficiency of the Management, 2. Implementation of Principles and Policies of the Management, 3. Find Variances, 4. Analyze the Reasons for Variances and 5. Recommend Suggestions for Improvement.

Management Audit is required for 1. Verifying the efficiency at all levels of management and implementation of policies. 2. Giving suggestion for Increase in efficiency, 3. Assessing the effectiveness of planning and policies, 4. Helping to increase profitability by giving remedies to maximize the organization's resources in an efficient way, 5. Helping to co-ordinate activities, 6. Giving Valuable Advice by scanning the management efficiency and detecting the weak spots of different levels of management, 7. Scrutinizing the Plans, Policies and Procedure to reach the organizations goal.

2.3.10 Business Process-re-engineering

Business process re-engineering (BPR) is a business management strategy, originally pioneered in the early 1990s, focusing on the analysis and design of workflows and business processes within an organization. BPR aimed to help organizations fundamentally rethink how they do their work in order to dramatically improve customer service, cut operational costs, and become world-class competitors.

BPR seeks to help companies radically restructure their organizations by focusing on the ground-up design of their business processes. According to early BPR proponent Thomas Davenport (1990), a business process is a set of logically related tasks performed to achieve a defined business outcome. Re-engineering emphasized a holistic focus on business objectives and how processes related to them, encouraging full-scale recreation of processes rather than iterative optimization of sub-processes.

Companies use Business Process Reengineering to reduce costs and cycle times and improve quality. Business Process Reengineering reduces costs and cycle times by eliminating unproductive activities and the employees who perform them. Reorganization by teams decreases the need for management layers, accelerates information flows and eliminates the errors and rework caused by multiple handoffs. Business Process Reengineering improves quality by reducing the fragmentation of work and establishing clear ownership of processes. Workers gain responsibility for their output and can measure their performance based on prompt feedback.

2.3.11 Activity Based Management (ABM)

Activity-based management (ABM) is used to determine the profitability of every aspect of a business, so that those areas can be upgraded or eliminated. The intent is to achieve a more fine-tuned organization with a higher level of profitability. The information used in an ABM analysis is derived from activity-based costing, where general overhead costs are assigned to cost objects based on their use of activity drivers. A cost object is anything about which a business wants to collect cost information, such as processes, customers, products, product lines, and geographic sales regions.

The information derived from an ABM analysis can also be carried forward into a company's forecasting models and budgets, which gives management a better idea of the future prospects of the business

2.3.12 Life Cycle Costing

Life-cycle cost analysis (LCCA) is a tool to determine the most cost-effective option among different competing alternatives to purchase, own, operate, maintain and finally, dispose of an object or process, when each is equally appropriate to be implemented on technical grounds. For example, for a highway pavement, in addition to the initial construction cost, LCCA takes into account all the user costs, (e.g., reduced capacity at work zones), and agency costs related to future activities, including future periodic maintenance and rehabilitation. All the costs are usually discounted and total to a present-day value known as net present value (NPV). This example can be generalized on any type of material, product or system.

Life cycle costing is used for compiling all costs that the owner or producer of an asset will incur over its lifespan. The concept applies to several decision areas. In capital budgeting, the total cost of ownership is compiled and then reduced to its present value in order to determine the expected return on investment (ROI) and net cash flows. This information is a key part of the decision to acquire an asset. In the procurement area, the purchasing staff seeks to examine the total cost of ownership of an asset in order to place orders for those items that are the least expensive, in aggregate, to install, operate, maintain, and dispose of. In the engineering and production areas, life cycle costing is used to develop and manufacture goods that will have the least cost to the customer to install, operate, maintain, and dispose of. In the customer service and field service areas, life cycle costing is focused on minimizing the amount of warranty, replacement, and field service work that must be performed on products over their useful lives.

Life cycle costing is more heavily used by businesses that place an emphasis on long-range planning, so that their multi-year profits are maximized. An organization that does not pay attention to life cycle costing is more likely to develop goods and acquire assets for the lowest immediate cost, not paying attention to the heightened servicing costs of these items later in their useful lives.

2.3.13 Value Stream Mapping

Value Stream Mapping (VSM) is a lean technique used to analyze the flow of materials and information currently required to bring a product or service to a consumer. Value Stream Mapping works on the principle that Value is added only when our action or operation contributes to transform the materials into the product that the customer is willing to pay for [13].

The critical phrase in this definition is, "the customer is willing to pay for." If a company's customer walked through its process, how would that customer react? Every process the customers sees involves work that adds value in their eyes.

Unfortunately, every process the customers sees also involves work for which they are not willing to pay - waste. While no one can eliminate all waste, using value stream mapping to identify waste helps determine a plan for eliminating it.

Objective of value stream mapping:

- Create a current state map analyses an overall process flow and present it in a visual form.
- Create a future-state map allowing the process to be re-designed to eliminate barriers (waste and unnecessary process) to flow.
- Develop and implement a plan to reach the future state by focusing all of process, functions and department also incorporate all of lean concepts and tools, such as takt time (cycle time based on customer demand), theory of constraints and pull-based scheduling systems.

Major benefits of VSM:

- Creates a common vision for everyone connected to the targeted value stream, of both current and future states
- Provides a visual map for ease of communications
- Allows waste to be seen by everyone so improvements can be focused
- Provides the foundation on which to base lean initiatives from the customer perspective

Steps of Value Stream mapping:

- Current stage map
- Future stage map
- Implementation plan

2.4 Literature review

Mancosu et al., 2018 applied Lean Six Sigma Methodology (LSSM) in oncology industry to provide near-perfect services by reducing improbable occurrence. LSSM was applied to redesign the 2D-2D breast repositioning process (Lean) by the retrospective analysis of the database (Six Sigma).

Breast patients with daily 2D-2D matching before RT (Radiotherapy) were considered. The five DMAIC (define, measure, analyze, improve, and control) LSSM steps were applied. The process was retrospectively measured over 30 months (7/2014–12/2016) by querying the RT Record & Verify database. Two Lean instruments (Poka-Yoke and Visual Management) were considered for advancing the process. The new procedure was checked over 6 months (1–6/2017).

14,931 consecutive shifts from 1342 patients were analyzed. Only 0.8% of patients presented median shifts >1 cm. The major observed discrepancy was the monthly percentage of fractions with almost zero shifts (AZS = 13.2% ± 6.1%). Ishikawa fishbone diagram helped in defining the main discrepancy con-causes. Procedure harmonization involving a multidisciplinary team to increase confidence in matching procedure was defined. AZS was reduced to 4.8% ± 0.6%. Furthermore, distribution symmetry improvement and outlier reduction, verified by Kurtosis diminution, demonstrated a better "normalization" of the procedure after the LSSM application.
Sugiyama et al., 2014 used Computer Aided Process Engineering (CAPE) along with lean framework to achieve Quality and Cost-Effectiveness in Pharmaceutical Production Processes instead of adopting so-called "continuous improvement" for retrofitting production and business processes even under strong constraints of quality regulations [14].

Kasava et al., 2015 used A conceptual hybrid framework integrating lean manufacturing with sustainable manufacturing theories, known as sustainable domain value stream mapping (SdVSM) in aircraft maintenance for sustainable cost reduction [15]

Lean approach with the integration of six sigma methodology through DMAIC process will be applied in natural gas processing industry in target of establishing cost reduction in this study.

2.5 Natural gas processing

The aim of natural gas production and processing activities is to produce a saleable natural gas product that meets the applicable gas transmission and distribution specifications. Typical sales specifications require that the natural gas be supplied at a specific pressure and satisfy gas quality requirements with respect to hydrocarbon dew point, water dew point, Sulphur content, and heating value.

Natural gas processing is a complex industrial process designed to clean raw natural gas by separating impurities and various non-methane hydrocarbons and fluids to produce what is known as 'pipeline quality' dry natural gas. The composition of the raw natural gas extracted from producing wells depends on the type, depth, and location of the underground deposit and the geology of the area. Oil and natural gas are often found together in the same reservoir.

The natural gas produced from oil wells is generally classified as “associated-dissolved,” meaning that the natural gas is associated with or dissolved in crude oil. Natural gas without any association with crude oil is classified as “non-associated”. Most natural gas production contains, to varying degrees, small (two to eight carbons) hydrocarbon molecules in addition to methane. Although they exist in a liquid state at underground pressures, these molecules will become gaseous at normal atmospheric pressure. Collectively, they are called condensates or natural gas liquids (NGLs). Natural gas is termed sweet gas when relatively free of hydrogen sulfide and called as a sour gas when hydrogen sulfide is present.

Natural gas processing plants purify the raw natural gas produced from underground gas fields or extracted at the surface from the fluids produced from oil wells. A fully operational plant will deliver pipeline-quality natural gas that can be used as fuel by residential, commercial and industrial consumers. Contaminants have been removed and heavier hydrocarbons have been extracted for commercial purposes.

Lean approaches for cost reduction have been vastly used in batch processing e.g. automobile manufacturing industries like Toyota, line manufacturing e.g. garments, pharmaceuticals industries, discrete manufacturing e.g. aircraft industry and medical technologies e.g. Oncology but this approach is going to be used first time in continuous production process like upstream natural gas processing industry in this study.

2.6 Lean manufacturing

U.S manufacturing has always searched for efficiency strategies that help to reduce costs, improve output, establish competitive position, and increase market share. Early process-oriented mass production manufacturing methods common before second world war shifted afterword result-oriented, output-focused, production system that control most of today's manufacturing business [16].

During II world war, the economic condition of Japan was heavily destroyed. Due to this there was scarcity of fund resulting in limiting access to corporate finance. In this situation, neither Toyota was able to set up a mass production system like their American counterparts, nor it was possible to layoff the employees to reduce their cost due to legislation. Anyhow Toyota had to devise a new system for reducing costs to sustain in the market. So, they decided to produce a small batch of products, which would reduce inventories; it means they would need less capital to produce the same product. But this is obstructed by the practical difficulty of changing tools and production lines frequently. To cope with this problem, they started making multipurpose tooling systems in their machines and trained their employees in changeover time reduction methods. At the same time, Toyota realized that investing in people is more important than investing in bigger size machinery and continues employee training throughout the organization. This motivates all employees, they are more open to the improvement process, and everyone started giving their input to the company.

In this way, short production runs started by Toyota became a benefit rather than a burden, as it was able to respond much more rapidly to changes in demand by quickly switching production from one model to another. Toyota did not depend on the economies of scale production like American companies. It rather developed a culture, organization and operating system that relentlessly pursued the elimination of waste, variability and inflexibility. To achieve this, it focused its operating system on responding to demand and nothing else. This in turn means it has to be flexible; when there are changes in demand, the operating system is a stable workforce that is required to be much more skilled and much more flexible than those in most mass production systems are. Over time, all these elements were consolidated into a new approach to operations that formed the basis of lean or Toyota Production System or Lean Production [17].

The lean manufacturing concept was popularized in American factories. One of the foremost studies by Massachusetts Institute of Technology on the movement from mass production toward production as described in the machine That changed the world, (Womack, Jones & Roos, 1990), which discussed the significant performance gap between Western and Japanese automotive industries. This book described the important elements accounting for superior performance as lean production. The term "lean" was used because Japanese business methods used less human effort, capital investment floor space materials, and time in all aspects of operations. The resulting competition between U.S. and Japanese automakers over the last 25 years has led to the adoption of these principles within all U.S. manufacturing businesses [18].

This segment gives an overall idea about historical background of lean manufacturing. It also provides a clear overview about development of lean manufacturing and integration to wide range or industry. Next segment will discuss the process overview of natural gas plant that will help to understand the application of lean approach and techniques in it.

2.7 Relation of six Sigma with lean

Six Sigma (6σ) is a set of techniques and tools for process improvement. It is a disciplined, data-driven approach and methodology for eliminating defects (driving toward six standard deviations between the mean and the nearest specification limit) in any process – from manufacturing to transactional and from product to service.

Lean management and Six Sigma are two concepts which share similar methodologies and tools. Both programs are Japanese-influenced, but they are two different programs. Lean management is focused on eliminating waste using a set of proven standardized tools and methodologies that target organizational efficiencies, while Six Sigma's focus is on eliminating defects and reducing variation. Both systems are driven by data though Six Sigma is much more dependent on accurate data.

CHAPTER 3

THEORITICAL FRAMEWORK

3.1 Introduction

Theoretical Framework chapter introduces the concrete weapons for this thesis. The term lean manufacturing is easy to define but implementation is not so easy in real practice. As different organization has different environment and implementation is not similar at different situation, it takes some time to understand lean manufacturing. This chapter will clarify all the lean six sigma applying tools & their implementation strategies to provide a brief idea about lean manufacturing. Most of the texts are obtained from different books, conference papers, journals and vendor documents of case study company; some relevant thesis works also helped in this regard.

For this research, a total number of 03 (three) cases were modeled, incorporating change in a natural gas plant's Charcoal filter consumption, varying absorbent (Tri-ethylene glycol) flow rate and tuning Re-boiler still column temperature. In this study, a lean six sigma approach has been applied in country's largest natural gas plant's gas dehydration process by using different tools like DMAIC model (Define, Measure, Analyze, Improve & Control), BOAT model (Barrier, Opportunity, Action & Threat), COPQ (Cost of Poor Quality) calculation, PICK chart (Possible, Implement, Challenge and Kill). Applying these tools, absorbent (TEG) loss and carbon filter replacement frequency has been reduced in atmospheric condition of Bangladesh and operational cost reduced.

3.2 What Is DMAIC?

When most people refer to Six Sigma, they are in fact referring to the DMAIC methodology. The DMAIC methodology should be used when a product or process is in existence at your company but is not meeting customer specification or is not performing adequately.

The DMAIC methodology is almost universally recognized and defined as comprising of the following five phases: Define, Measure, Analyze, Improve and Control. In some businesses, only four phases (Measure, Analyze, Improve and Control) are used.

In this case the Define deliverables are then considered pre-work for the project or are included within the Measure phase.

The DMAIC methodology breaks down as follows:
Define the project goals and customer (internal and external) requirements.
Measure the process to determine current performance.
Analyze and determine the root cause(s) of the defects.
Improve the process by eliminating defect root causes.
Control future process performance.

The first step is to define the background by selecting particular problem for resolution depending on VOC (Voice of customer). Also, it is required to define clear, concise problem statement including the magnitude of the problem, process location, and the problem's impact on the business using "As is-To Be" Process map.

The second step is to measure the current condition by detailing the specifics of the current-state process and measuring what is the problem and where is the problem. Also, it is required to determine process capability and review baseline performance with set target.

The third step is to analyze whether the taken steps work or not by using data and evidence in a thorough and objective review. Also, it is required to validate the course of actions performance and effectiveness. It is must to document all solutions to solve these causes.

The fourth step is to determine magnitude of improvement by evaluating financial gains. Also, it is required to calculate the success of taken lean steps by COPQ (Cost of poor quality) or cost benefit analysis.

The fifth step is to control the improvement result and follow up for sustainability. It is required to deploy the infrastructure for sustaining the gains (such as standardization, audits, dashboards and reviews) and share findings across the organization/enterprise as appropriate.

3.3 Sixteen steps to complete DMAIC

3.3.1 Define:

1. Who are your customers for the assigned project? What is the business case? What are the deliverables for the project? What Metrics to capture?
2. What are the major steps in the process? Does the project need to be scoped?
3. How have you prioritized improvement opportunities? Who are the stakeholders in the process? Whom are the team members working on these improvements? What are the goals and timeline for the project? Is this an opportunity for a Kaizen?

3.3.2 Measure:

4. What is the current state of the process? Is the process constrained?
5. How is the process measured? Is the measurement precise? Accurate?
6. What is the baseline for the key performance metrics? What are the specifications of the process? Is it capable?

3.3.3 Analyze:

7. What types of waste are apparent in the process? Are the primary metric(s) off target? Does it exhibit high variation?
8. What are the sources of the problem? Root causes?
9. What would a benchmark or "world class" process look like?

3.3.4 Improve:

10. How can we remove the cause of the waste? How do the inputs to the process affect it? Do they interact?
11. What is the list of improvements to be made? Are tests necessary? Is there a risk in implementing them?
12. What is the performance of the improved process? Did you meet your goal?
13. What is the Cost of Poor Quality?

3.3.5 Control:

14. How will you sustain the improvement?

15. What is the benefit from the improved process? Is it documented?
16. Has the team been rewarded?

3.3.6 Tools used in DMAIC

Table 3.1: List of tools used in DMAIC process

DEFINE	MEASURE	ANALYZE	IMPROVE	CONTROL
• Input Process Output Diagram (IPO) • Customer Interview • Problem statement • Affinity diagram • Process Map • Cascading IPO • Pareto Charts • Failure Mode & Effects Analysis (FMEA) • Gantt Chart • Kaizen Plan • Kano Model	• Process Flow Diagram (PFD) • Value Stream Map (VSM) • Physical Flow Map • Constraint Map • Measurement System Analysis (MSA) • Histograms • Control Charts • Box Plots • Capability Study • CpK Analysis • Cost Data • Customer Interview (VOC and VOB)	• Kaizen • Takt time • 5S • Line balancing • Cause & Effect Diagram • Root cause analysis • Pareto Chart • Analysis of Variance (ANOVA) • Correlation Analysis • T-tests, F-test, CHI • Squared tests • Voice of Customer (VOC) • Voice of the Business (VOB) • Run Charts	• Pull System • Layout Design • Quick Changeover • Mistake Proofing • Standard Work • Scatter Plots • Design of Experiments (DOE) • Prioritization Matrix • Solution Grid • Pugh Matrix • Process Capability • Run Charts • Box Plot • Overall Equipment Effectiveness • Failure Mode & Effects Analysis	• Control charts • Control Plans • Error Proofing • Accountability • 5S audit • Financial verification • Communication Plan • Final Project Presentation

3.4 PI Software

The PI System is a suite of software products that are used for data collection, historicizing, finding, analyzing, delivering, and visualizing. It is marketed as an enterprise infrastructure for management of real-time data and events.

OSIsoft, LLC is a manufacturer of application software for real-time data management, called the PI System. Founded in 1980, OSIsoft is privately held and headquartered in San Leandro, California. OSIsoft develops and supports software used to capture, process, analyze, and store any form of real-time data. OSIsoft's target markets include: oil and gas; chemicals and petrochemicals; materials, mines, metals and metallurgy; power and utilities; pulp and paper; pharmaceuticals, food and life sciences; critical facilities, data centers and IT; and federal.

Data can be automatically collected from many sources (control systems, lab equipment, calculations, manual entry or custom software) by PI. Most information is gathered using one of the many OSIsoft and third-party PI Interfaces. Users can then access this information using a common set of tools (such as Microsoft Excel, web browser or PI Process Book) and look for correlations. Some examples include:

- Analyzing seasonal trends
- Determining if utilities are meeting the demands of production
- Comparing the performance of different lots of raw material
- Determining when maintenance is required on equipment
- Optimizing the utilization or performance of a production line

3.4.1 Functions of PI software

PI works as one home for all operational data in a natural gas processing plant or any chemical plant. Production, maintenance, Drilling, Assed Development and Planning department can see, analyze and store information in real time & historically. It allows for collaboration and joint troubleshooting between head office and plant locations; feeds data to analytical tools gives calculations and trend analysis to process operators to run plant operations smoothly with at a glance visualization of demand trends.

3.4.2 PI tag

A tag is a reference to a unique location where data from a given point is stored.
Examples:

- Flow rate from a meter run.
- Status of a digital setting.
- Temperature or pressure from an end device.
- Reason code for manually entered data.
- Results of a totalizer or calculation function.

3.4.3 PI Process Book

PI Process Book is a user-friendly graphics package that allows users to incorporate real-time data into interactive displays. It has customizable trending capabilities, alerting options to identify potential problems. It can build in specialized functionality using the Visual Basic development environment. It is a software tool used to display data in a graphical manner. A display can be created with single values, trends, x-y plots and other items, and populated with data from the PI or AF Server. It is mainly used by end-users as a comparison or monitoring tool. Additional functionality can be applied to Process Book through the use of custom scripts developed with an embedded version of Visual Basic for Applications.

3.4.4 How PI system works

The PI Server is the real-time data storage and distribution engine that powers the PI System and provides a comprehensive real-time and historical view into operations, enabling users to make timely and impactful decisions. The PI Server is the heart of the PI System. It collects, stores, and organizes data from all your data sources, providing a powerful and flexible information infrastructure for your organization. The PI Server also includes sophisticated tools for analytics, alerts, and auditing. You can connect the PI Server to almost any existing automation, lab, or information system. Operators, engineers, managers, and other plant personnel use a variety of client applications to connect to the PI Server to view data stored in the PI Server or in external data archive systems. The PI Server is a suite of products.

The PI Data Archive is a component of the PI Server that provides efficient storage and archiving of time series data. It is the cornerstone of the PI System and your data infrastructure, enabling high-performance data storage and retrieval by client software. The PI Data Archive collects, stores, and organizes data from data sources, providing an information infrastructure. The PI Server also includes tools for analytics, alerts, and auditing. The PI Server may be connected to almost any existing automation, lab, or information system. Operators, engineers, managers, and other plant personnel can use client applications to connect to the PI Server to view data stored in the PI Server or in external data archive systems.

PI Asset Framework AF allows the definition of consistent representations of organizational assets and/or equipment and uses these representations in analyses that yield critical and actionable information.

PI Data Link is an Add-in to Excel for tabular data analysis. Provides an end-user the ability to import data from the PI or AF Server for manipulation, comparison, or report generating. Data can be imported in a variety of ways including archived, calculated, and filtered data.

The PI Web API is a restful interface to the PI system. It gives client applications read and write access to their PI Asset Framework and PI Data Archive over HTTPS.

PI Vision is a simple web-based tool for quick ad hoc displays. PI Vision is a thin client tool and can be used anywhere an Internet connection is available, as opposed to the other end-user tools that are considered fat client and require a local installation. Prior to March 2017, PI Vision was called PI Core sight.
PI Connectors and PI Interfaces are designed to gather data from a data source, convert to a PI readable format, and send to the PI Data Archive to be stored. Unlike Interfaces, Connectors are able to collect and send metadata to the PI Asset Framework in addition to real-time data. The most common PI Interfaces are OPC, PI to PI, Modbus, RDBMS, and Universal File Loader (UFL).

PI Integrators are a line of web-based applications that prepare and send time-series data to third-party analytics platforms. The PI Integrator cleanses, augments, shapes, and transmits data from PI into common business intelligence and data warehouse tools, such as Power BI, Tableau, Hadoop, Microsoft Azure, and Amazon Web Services. Current products include the PI Integrator for Esri ArcGIS, PI Integrator for Business Analytics and PI Integrator for SAP HANA.

3.5 Cost of Poor Quality (COPQ)

Cost of poor quality (COPQ) are costs that would disappear if systems, processes, and products were perfect. COPQ was popularized by IBM quality expert H. James Harrington in his 1987 book *Poor Quality Costs* [19]. COPQ is a refinement of the concept of quality costs. In the 1960s, IBM undertook an effort to study its own quality costs and tailored the concept for its own use. While Feigenbaum's term "quality costs" is technically accurate, it's easy for the inexperienced to jump to the conclusion that better-quality products cost more to produce. Harrington adopted the name "poor quality costs" to emphasize the belief that investment in detection and prevention of product failures is more than offset by the savings in reductions in product failures.

The Cost of Poor Quality (COPQ) quantifies the negative outcomes due to waste, inefficiencies and defects in a process. Quality great Joseph Juran separated these costs into 3 categories [20].

3.5.1 Prevention Costs

Avoiding any defect to take place is the most proven way to handle the cost of quality. This is what prevention cost is all about. Preventing issues and defects from happening is more cost effective than finding solutions once these took place. In short, prevention costs relate **to** all activities that are meant to trim down or eliminate defects. It is including quality planning, training, preventive maintenance, housekeeping etc.

3.5.2 Appraisal Costs

All defects in the products or services must be detected in an early time frame throughout the process of production. This is where appraisal costs will enter the picture. Also known as ″inspection cost″, it is used to spot defects prior to the delivery to customers. However, performing such activities does not guarantee that defects will not take place. This leads to the fact that even the use of many inspectors cannot lead to 100 percent quality. Plus, this approach in quality cost is expensive and ineffective in that defects can be overlooked.

To resolve this, most current organizations realize the importance of quality control on the part of their employees. All employees should be accountable for quality control. This measure, along with improving the design and easy manufacturing of products, contributes to better quality control, rather than relying solely on human inspection. It includes testing, inspection, audits, reviews and surveys, etc.

3.5.3 Failure Costs

It is segregated in two parts; internal failure cost and external failure cost.

3.5.3.1 Internal Failures: Failure costs exist every time products fall short to the specified design. Internal failure costs are generated from detecting defects prior to shipping. This type of cost may involve rejected and scrap products, fixing defective items as well as downtime brought by problems in quality. In some cases, this type of quality cost also includes review of materials, material downgrades and re-testing.

An organization with a more efficient appraisal approach has a better chance of identifying issues internally. This also means improved internal failure costs. With a better internal failure cost strategy in place, gigantic costs of external failure can be prevented. It includes scrap, rework, expediting, equipment downtime, injuries, etc.

3.5.3.2 External Failures: External failure cost occurs when defective items are shipped to customers. This may cover costs like product recalls, warranty repairs, product replacements, and legal issues, as well as lost profits brought about by poor reputation. These costs can be devastating to an organization's revenues; thus, these are the costs that are acquired once the products have already been shipped.

In the past, managers tended to rely on warranty evaluations too much when it came to handling problems with products. Shipping items to customers without dwelling much on quality control measures resulted in great external failure costs, as well as a decline in profits and market share – and customers' ill spirits.

Including product recalls, returned products, complaint handling, lost sales, etc. COPQ is often represented as a dollar amount (or as a percentage of sales) and is composed of the categories listed above. The goal of any organization is to reduce COPQ to zero.

3.5.4 Strategies to lowering COPQ

Here are nine strategies that can help you lower your cost of poor quality

3.5.4.1 Clear Product and Process Traceability

One way to cut down your costs of poor quality is to improve the visibility into your product quality, as well as the processes involved in manufacturing and distributing your product. Without good traceability in products and processes, organizations are more susceptible to product delays, defects, and recalls, and process breaches. Additionally, ensuring clear product and process traceability helps you shorten the time to track down root causes and identify the stage at which the defect was caused.

Organizations have adopted automated tools to gain visibility into the various stages of their internal and supplier's processes, as well as to map all their processes to various stages of a product life cycle from production to delivery. You can view and access details on production location, time of production, warehouse, labeling and packaging, and delivery related information with readily available reports to have better insight.

3.5.4.2 Closed-Loop Nonconformance and Corrective Action Program

Remediating problems is one of the key aspects to curb costs of nonconformance arising from production deviations, errors in specifications, quality incidents, or customer complaints. Automating a closed-loop nonconformance and corrective action plan can help you take immediate containment actions like production stop and sales or distribution stop, preventing product rework or recall and further costs. Industry-standard methodologies such as 8D, 5-Why, Ishikawa, FMEA, and more, can be adopted to identify root cause of a non-conformance based on respective business needs, Appropriate Corrective and Preventive Actions (CAPA) can be planned, implemented, and tracked until completion. Implementing proactive quality measures can help you keep you abreast of any gaps and ensuring a proper effectiveness check can be performed to ensure that the problem has been resolved.

3.5.4.3 Systematic Preventive Maintenance Procedures

Following diligent preventive maintenance procedures can help you assess potential losses, estimate the frequency of failure and work towards minimizing it, with an optimal maintenance policy. Rather than spending time and money over maintenance of a facility, machine, transport vehicle, or equipment after a defect is noticed, many organizations are moving toward a proactive way to mitigate any lag due to break-down of machines during production. This helps avert loss or cost incurred due to delayed production or distribution.

Automated tools can simplify the process of calculating metrics on the cost of maintenance for inventory owners and quality assurance teams, in addition to consolidating equipment and facility maintenance histories. This enables you to make precise improvements and reduce your cost of poor quality. Additionally, a centralized repository to store and organize all types of documents such as manuals, directives, etc. gives you access to data from across your organization to make timely and informed decisions.

3.5.4.4 Periodic Internal Quality Audit

Internal quality audit is important for organizations to keep a tab on non-conformities, if any, in products or processes. This helps you notice any loopholes in or deviations from quality requirements, which can be mitigated from source at the earliest. When quality issues go unnoticed, your organization's COPQ can increase, and in the long run it can snowball into a disaster, affecting your bottom line.

The best way to tackle this is to implement a quality audit solution that facilitates a federated approach to managing different types of internal quality audits such as factory audits, process audits, facility audits, and health & safety audits, which helps in boosting operational excellence and ensuring adherence to the industry standards of quality. It would also enable you to completely manage quality audit processes right from audit planning and scheduling, to audit execution and issue management.

3.5.4.5 Seamless Change Management Process

While an organization's ability to handle change has been often criticized, successful change management depends on strong leadership and clear policies. With changes, come many risks and uncertainties. A well-defined and streamlined process will ensure that these changes are implemented successfully with minimal disruption and risk.

Often a technology solution can provide you with the capabilities to manage changes in equipment, processes, as well as documents. You will be able to chart out your change management process from the initiation stage to tracking change requests, identifying its impact and risk on associated processes, and improving overall coordination among various departments affected by the change. You will have clear visibility into the whole process, including change history, and data on the changes made, their status, and departments or regions affected, along with associated costs.

3.5.4.6 Aggregated Customer Complaints and Timely Return Management

When it comes to customers, their satisfaction of your product is what will keep your organization growing and your bottom line rising. Ensuring that they are happy is often a tricky business. To stay on top of things, it is essential for you to keep track of all customer complaints, analyze them, and provide prompt remedial responses. There is a lot of learning an organization can take away from assessing the nature and frequency of the complaints they receive and make decisions based on the actions taken for similar complaints in the past.

An efficient complaints management tool should be able to help you analyze the complaint, mapping it to corresponding risks, policies, and even compliance activities. It will also provide you with the analytics and business intelligence you need to carry further investigations, notify relevant personal, and track remedial actions. Capturing and managing all the complaints from various sources will help organizations be aware of arising issues and implement corrective and preventive measures.

3.5.4.7 Streamlined Supplier Quality Program

Suppliers can generally affect your COPQ by producing defective material and/or finished products. Any loopholes in a supplier’s process would have a direct effect on your organization’s brand and revenue. For organizations with a large supply chain network, the COPQ of individual suppliers participating within a supply chain has a cumulative effect on the overall revenue of the organization. As a result, you would do well if you work proactively with your suppliers to reduce your COPQ.

Many organizations are also implementing supplier charge-backs (or cost recovery) process, wherein the supplier is charged for any additional costs incurred due to non-conforming components and materials, as well as late deliveries. An effective charge-back system can help you keep track of all the metrics related to your suppliers' performance, along with ensuring business discipline and accountability throughout the supply chain.

3.5.4.8 Effective Training for Employees and Suppliers

Maintaining and nurturing the knowledge base of employees and suppliers is one of the crucial elements of taking a step toward reducing your COPQ. All personnel need to be up to speed with policies, SOPs, regulations, and other relevant quality metrics, so that violations are kept at bay. By providing periodic training sessions, tests, and awareness programs for your employees and suppliers, you can ensure all of the components of your business ecosystem are on the same page, moving toward achieving a unified objective.

With an introduction of any new policy or guideline, a training management program can trigger notifications to appropriate stakeholders to complete relevant training courses and also provide a training guide. A streamlined training process helps reduce risks and non-compliance gaps. You can also test the effectiveness of your training program through tests and questionnaires, and any gaps can be bridged with additional training courses.

3.5.4.9 Electronic Records and Documentation Management

To make sure that employees and suppliers are up-to-date with relevant policies, contracts, SOWs, SOPs, guidelines, regulations, and other such documents, you need to be able to store them in a centralized location with applicable access rights. This may require you to leverage an integrated system to manage quality documents right from its inception to its communication and implementation, including the various versions that a document would go through. This helps employees and suppliers follow set processes and policies, reducing the likelihood of nonconformity, product defects, and rework costs. A system that can scale with your organization will allow you to support policy management at a local, regional, and organizational level.

To reduce COPQ, it is needed to look at it from an overall organization perspective. Addressing quality issues in a holistic and proactive way helps you identify the areas of concern, which may accrue to a high COPQ. This approach not just aggregates all possible issues across the length and breadth of your processes, but it also helps define preventive measures and maps it to the end result. Before it is too late, this enables you to quickly assess what is going right or wrong and what can be done about it.

3.6 What is EIS and how to develop?

The Executive Summary is a one-page document that summarizes the purpose, goals, and approach of design project. Reading this summary should give any evaluator a clear idea of the problem that is being tackled, approach to solving it and roughly where the project owner is in the process [21].

After reading the summary, audience should understand the main points and evidence for those points without having to read every part of report in full. That is why these are called executive summaries. The audience is usually someone who makes funding, personnel, or policy decisions and needs information quickly and efficiently. It is to remember that the purpose is to provide an overview or preview to an audience who may not have time to read the full report, understand calculations; only bother to end-benefit.

Guidelines for writing executive summaries:

- An executive summary should explain why you wrote the report, emphasize your conclusions or recommendation, and include only the essential or most significant information to support those conclusions.
- Executive summaries are usually organized according to the sequence of information presented in the full report, so follow the order of your report as you discuss the reasons for your conclusions. Consider using headings that match the headings in your full report.
- Executive summaries are usually proportional in length to the larger work they summarize, typically 10-15%. Most executive summaries are 1-2 pages.

▪ Write the executive summary after you have completed the report and decided on your recommendations. Look at the first and last sentences of paragraphs to begin to outline your summary. Find key words and use those words to build active sentences. Use transition words that express causation (therefore, consequently), words that signal essentials (basically, central, leading, principal, major), and contrast (however, similarly, more than, less likely).

▪ Make the summary concise but be sure to show why you arrived at your conclusions.

▪ Executive summaries should communicate independently of the report. Ask someone not familiar with the report to read your executive summary to see if it makes sense.

3.7 PICK chart

A PICK chart is a Lean Six Sigma tool, developed by Lockheed Martin, for organizing process improvement ideas and categorizing them during the Identify and Prioritize Opportunities Phase of a Lean Six Sigma project [22]. This chart is a method to prioritize a number of action items or problem-solving ideas. A pick chart allows visual comparison of action items relative to their impact to the problem being addressed vs. the ease/cost of implementation. In very rudimentary terms, PICK charts are a Return on Investment (ROI) method.

When faced with multiple improvement ideas a PICK chart may be used to determine the most useful. There are four categories on a 2X2 matrix; horizontal is scale of payoff or benefits), vertical is ease of implementation. By deciding where an idea falls on the pick chart, four proposed project actions are provided: Possible, Implement, Challenge and Kill; thus, the name PICK.

- Possible - ideas that are easy to implement but have a low payoff.
- Implement - ideas that are easy to implement and a high payoff.
- Challenge - ideas that are hard to implement and difficult to determine payoff.
- Kill - ideas that are hard to implement and have low payoff.

The vertical axis, representing ease of implementation would typically include some assessment of cost to implement as well. Actions that are more expensive can be said to be more difficult to implement.

Once each idea from the brainstorming session has been placed on the most appropriate square, it becomes easier to identify which ideas should be acted on first. In a group setting, PICK charts are useful for focusing discussion and achieving consensus.

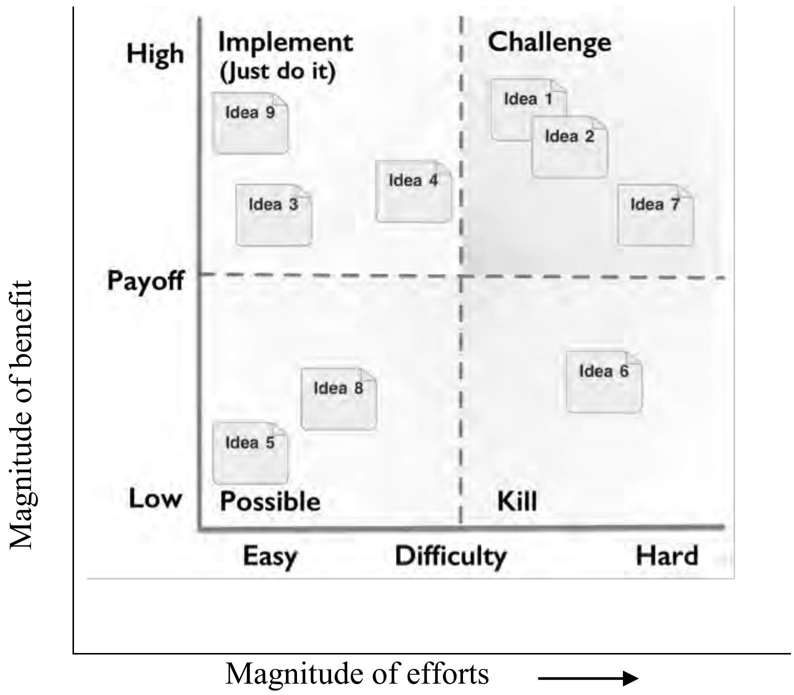

Fig 3.1: PICK chart framing [22]

3.8 IPO (Input–Process–Output) Model

The input–process–output (IPO) model, or input-process-output pattern, is a widely used approach in systems or process analysis and software engineering for describing the structure of an industrial process or information-processing program. Many introductory programming and systems analysis texts introduce this as the most basic structure for describing a process [23].

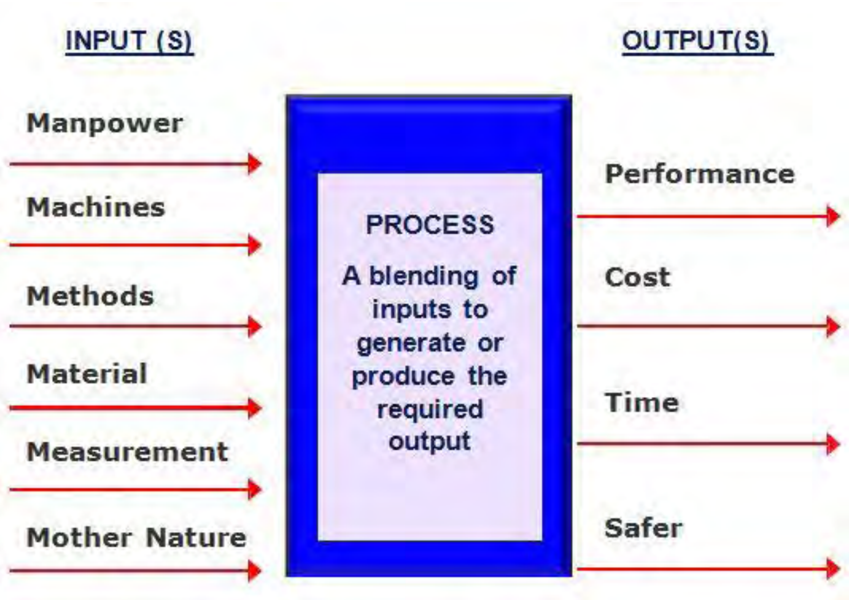

Fig 3.2: IPO (Input–Process–Output) Model method

3.9 Definition of AFB

Accrued Financial Benefit (AFB); another name hard dollar; is a reasonable estimation of the value created by a lean six-sigma project. Valuation of process improvements is for the 12 months succeeding the Control Phase Gate. Improvements in processes are typically at a level of detail not reflected by financial accounting.

3.10 PID controller tuning

A proportional–integral–derivative controller (PID controller or three-term controller) is a control loop feedback mechanism widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value $e(t)$ as the difference between a desired setpoint (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively), hence the name.

In practical terms it automatically applies accurate and responsive correction to a control function. An everyday example is the cruise control on a car, where external influences such as hills (gradients) would decrease speed. The PID algorithm restores from current speed to the desired speed in an optimal way, without delay or overshoot, by controlling the power output of the vehicle's engine.

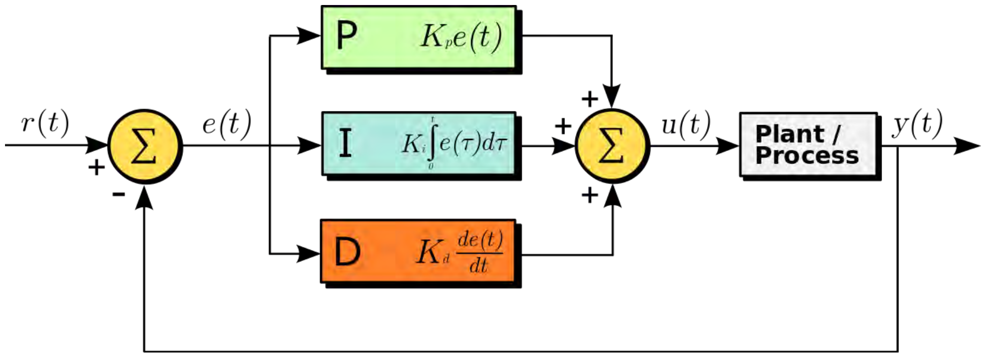

Fig 3.3: A block diagram of a PID controller in a feedback loop. r(t) is the desired process value or setpoint (SP), and y(t) is the measured process value (PV).

In this model, term P is proportional to the current value of the SP − PV error e(t). For example, if the error is large and positive, the control output will be proportionately large and positive, taking into account the gain factor "K". Using proportional control alone in a process with compensation such as temperature control, will result in an error between the setpoint and the actual process value, because it requires an error to generate the proportional response. If there is no error, there is no corrective response. Term I accounts for past values of the SP − PV error and integrates them over time to produce the I term. For example, if there is a residual SP − PV error after the application of proportional control, the integral term seeks to eliminate the residual error by adding a control effect due to the historic cumulative value of the error. When the error is eliminated, the integral term will cease to grow. This will result in the proportional effect diminishing as the error decreases, but this is compensated for by the growing integral effect.

Term D is a best estimate of the future trend of the SP − PV error, based on its current rate of change. It is sometimes called "anticipatory control", as it is effectively seeking to reduce the effect of the SP − PV error by exerting a control influence generated by the rate of error change. The more rapid the change, the greater the controlling or dampening effect [24].

Tuning is the balance of these effects which is achieved by "loop tuning" to produce the optimal control function. The tuning constants are shown below as "K" and must be derived for each control application, as they depend on the response characteristics of the complete loop external to the controller. These are dependent on the behavior of the measuring sensor, the final control element (such as a control valve), any control signal delays and the process itself. Approximate values of constants can usually be initially entered knowing the type of application, but they are normally refined, or tuned, by "bumping" the process in practice by introducing a setpoint change and observing the system response [25].

The mathematical model and practical loop above both use a "direct" control action for all the terms, which means an increasing positive error results in an increasing positive control output for the summed terms to apply correction. However, the output is called "reverse" acting if it is necessary to apply negative corrective action. For instance, if the valve in the flow loop was 100–0% valve opening for 0–100% control output – meaning that the controller action has to be reversed. Some process control schemes and final control elements require this reverse action. An example would be a valve for cooling water, where the fail-safe mode, in the case of loss of signal, would be 100% opening of the valve; therefore 0% controller output needs to cause 100% valve opening.

There are three popular methods for PID tuning:

1. Ziegler Nicholls tuning method 2. Cohen & Coon tuning method 3. Rule of Thumb- tuning method

In this project Ziegler Nicholls tuning method has been used to tune the temperature control valve and eradicating overshoot of the controller.

3.10.1 Ziegler Nicholls tuning method

The Ziegler–Nichols tuning method is a heuristic method of tuning a PID controller. It was developed by John G. Ziegler and Nathaniel B. Nichols. It is performed by setting the I (integral) and D (derivative) gains to zero. The "P" (proportional) gain, Kp is then increased (from zero) until it reaches the ultimate gain Ku at which the output of the control loop has stable and consistent oscillations. Ku and the oscillation period Tu are used to set the P, I, and D gains depending on the type of controller used.

Table 3.2: Ziegler Nicholls tuning method

Control Type	K_p	K_i	K_d
P	$0.50K_u$	—	—
PI	$0.45K_u$	$0.54K_u/T_u$	—
PID	$0.60K_u$	$1.2K_u/T_u$	$3K_uT_u/40$

These gains apply to the ideal, parallel form of the PID controller. When applied to the standard PID form, only the integral and derivative time parameters Ti and Td are dependent on the oscillation period Tu.

3.10.2 Cohen & Coon tuning method

The Cohen-Coon tuning rules are suited to a wider variety of processes than the Ziegler-Nichols tuning rules. The Ziegler-Nichols rules work well only on processes where the dead time is less than half the length of the time constant. The Cohen-Coon tuning rules work well on processes where the dead time is less than two times the length of the time constant (and you can stretch this even further if required). Cohen-Coon provides one of the few sets of tuning rules that has rules for PD controllers – should you ever need this.

3.11 MOC (Management of Change)

Management of Change, or MOC, is a best practice used to ensure that safety, health and environmental risks are controlled when a company makes changes in their facilities, documentation, personnel, or operations.

When decisions and changes are made rapidly, safety and health risks can increase resulting in disasters such as explosions at the oil refinery and detergent plant described in the U.S. Chemical Safety and Hazard Investigation Board's 2001 "Management of Change" safety bulletin. There are many other notable examples of how even simple changes at a worksite have led to tragedy.

At worksites where highly hazardous chemicals are used, the Process Safety Management (PSM) rules apply and proper application of Management of Change is not just a best practice but is actually a requirement. In these cases, a MOC program is used to ensure all changes to a process are properly reviewed and any hazards introduced by the change are identified, analyzed, and controlled before resuming operation.

MOC often seems deceptively simple in concept but can be very effective in the prevention of accidents and can be used as a best practice at worksites where the Process Safety Management rule doesn't apply.

3.11.1 When is MOC used?

Generally, a business need or opportunity becomes a project or business solution and requires changes in the workplace that can affect processes, systems, people, or organizational structure. Think about whether implementing this change improves your safety program and makes good business sense.

One obvious benefit Management of Change gives is avoiding the consequences of unforeseen safety and health hazards through planning and coordinating the implementation of change in your facility. This is why Management of Change is required in the PSM rules when highly hazardous chemicals are used.

3.11.2 Benefits of MOC

- It minimizes unplanned adverse impacts on system integrity, security, stability, and reliability for the business process being altered or added.
- It maximizes the productivity and efficiency of staff planning, coordinating, and implementing the changes.

- It provides a stable production environment.
- It ensures the proper level of technical completeness, accuracy of modifications, and testing of systems before implementation.
- It provides an appropriate level of management approval and involvement.

3.11.3 Elements of an effective MOC Program

- Procedures that consider:
  - The technical basis for the proposed change.
  - Impact of the change on employee safety and health.
  - Modifications to operating procedures.
  - Time needed for the change.
  - Authorization required for the proposed change.
- Steps to identify hazards before the changes are made.
- Methods to screen and classify changes.
- Keys to identifying hazards in changes.
- Methods for documenting MOC reviews.
- Procedures to make approvals and authorizations workable.
- Plans to inform and train personnel about the changes.
- Methods for updating Process Safety Information, procedures and other Process Safety Management information.
- Steps for effective implementation.
- Procedures for reviewing and revising any existing MOC Program.

3.11.4 Best Practices in MOC

- Compile safety information on the products, equipment, materials or processes that are changing and write policies and procedures to incorporate the new information. Be sure to include information on how to investigate accidents, audit compliance with safety procedures and plan for emergency responses.

- Establish a way to gather employee input on the changes, such as interviews, group discussions or surveys. Incorporate employee comments and suggestions into your draft policy and procedures.

- Write instructions for all employees on every process in which changes are involved. The procedures must be clear, include steps for performing every operation, cover safety information, state what to do in the case of an emergency and be readily available to the employees performing the procedures.

- Train employees on the changes. Emphasize any safety and health hazards and what to do in the case of an emergency. The training must take place before an employee is allowed to operate the equipment or perform the job that the changes were related to.

- Establish written procedures for what you will do the next time you have a change in safety management.

3.12 Control valve and its operations

A control valve is a valve used to control fluid flow by varying the size of the flow passage as directed by a signal from a controller. This enables the direct control of flow rate and the consequential control of process quantities such as pressure, temperature, and liquid level.

The opening or closing of automatic control valves is usually done by electrical, hydraulic or pneumatic actuators. Normally with a modulating valve, which can be set to any position between fully open and fully closed, valve positioners are used to ensure the valve attains the desired degree of opening.
Air-actuated valves are commonly used because of their simplicity, as they only require a compressed air supply, whereas electrically-operated valves require additional cabling and switch gear, and hydraulically-actuated valves required high pressure supply and return lines for the hydraulic fluid.

An automatic control valve consists of three main parts in which each part exist in several types and designs:

- Valve actuator moves the valve's modulating element, such as ball or butterfly.

- Valve positioner ensures the valve has reached the desired degree of opening. This overcomes the problems of friction and wear.
- Valve body is the structure which contains the modulating element, a plug, globe, ball or butterfly.

Taking the example of an air-operated valve, there are two control actions possible:

- "Air or current to open" - The flow restriction decreases with increased control signal value.
- "Air or current to close" - The flow restriction increases with increased control signal value.

There can also be failure to safety modes:

- Air or control signal failure to close" - On failure of compressed air to the actuator, the valve closes under spring pressure or by backup power.
- Air or control signal failure to open" - On failure of compressed air to actuator, the valve opens under spring pressure or by backup power.

The fundamental function of a positioner is to deliver pressurized air to the valve actuator, such that the position of the valve stem or shaft corresponds to the set point from the control system. Positioners are typically used when a valve requires throttling action. A positioner requires position feedback from the valve stem or shaft and delivers pneumatic pressure to the actuator to open and close the valve. The positioner must be mounted on or near the control valve assembly. There are three main categories of positioners, depending on the type of control signal, the diagnostic capability, and the communication protocol: pneumatic analog and digital.

Processing units may use pneumatic pressure signaling as the control set point to the control valves. Pressure is typically modulated between 20.7 to 103 kPa (3 to 15 psig) to move the valve from 0 to 100% position. In a common pneumatic positioner the position of the valve stem or shaft is compared with the position of a bellows that receives the pneumatic control signal. When the input signal increases, the bellows expands and moves a beam. The beam pivots about an input axis, which moves a flapper closer to the nozzle. The nozzle pressure increases, which increases the output pressure to the actuator through a pneumatic amplifier relay. The increased output pressure to the actuator causes the valve stem to move. Stem movement is fed back to the beam by means of a cam. As the cam rotates, the beam pivots about the feedback axis to move the flapper slightly away from the nozzle. The nozzle pressure decreases and reduces the output pressure to the actuator. Stem movement continues backing the flapper away from the nozzle until equilibrium is reached. When the input signal decreases, the bellows contracts (aided by an internal range spring) and the beam pivots about the input axis to move the flapper away from the nozzle. Nozzle pressure decreases and the relay permits the release of diaphragm casing pressure to the atmosphere, which allows the actuator stem to move upward. Through the cam, stem movement is fed back to the beam to reposition the flapper closer to the nozzle. When equilibrium conditions are obtained, stem movement stops and the flapper is positioned to prevent any further decrease in actuator pressure.

The second type of positioner is an analog I/P positioner. Most modern processing units use a 4 to 20 mA DC signal to modulate the control valves. This introduces electronics into the positioner design and requires that the positioner convert the electronic current signal into a pneumatic pressure. In a typical analog I/P positioner, the converter receives a DC input signal and provides a proportional pneumatic output signal through a nozzle/flapper arrangement. The pneumatic output signal provides the input signal to the pneumatic positioner. Otherwise, the design is the same as the pneumatic positioner. While pneumatic positioners and analog I/P positioners provide basic valve position control, digital valve controllers add another dimension to positioner capabilities. This type of positioner is a microprocessor-based instrument. The microprocessor enables diagnostics and two-way communication to simplify setup and troubleshooting.

In a typical digital valve controller, the control signal is read by the microprocessor, processed by a digital algorithm, and converted into a drive current signal to the I/P converter. The microprocessor performs the position control algorithm rather than a mechanical beam, cam, and flapper assembly. As the control signal increases, the drive signal to the I/P converter increases, increasing the output pressure from the I/P converter. This pressure is routed to a pneumatic amplifier relay and provides two output pressures to the actuator. With increasing control signal, one output pressure always increases and the other output pressure decreases.

CHAPTER 4

CASE STUDY

4.1 Introduction

In natural gas processing plant the main course of action is to separate pure methane from moisture, water droplets, debris, hydrogen sulphide and condensate as well as higher hydrocarbons. After separating the pure methane gas, the main challenge is to dehydrate the gas in counter current absorption process with absorbent. For cost effectiveness, when the absorbent becomes heavier by absorbing moisture and water droplets from natural gas, it is then re-boiled to make it pure for re-use. Carbon filters are commonly used for purification of the absorbents. Therefore, absorbents and carbon filters are the basic materials which are to be outsourced in natural gas dehydration plant. Hence; focus of the case study was in lean approach to these two materials.

4.2 Studied Gas Field Profile

There are 22 natural gas plants in Bangladesh with total natural gas production capacity of 2750 MMSCFD. The studied gas field is in Block 12, discovered in 1998, This block is one of the most significant natural gas discoveries in Bangladesh in both quality and size of the reserve. With production starting in 2007, it is now the largest producing gas field in Bangladesh among the twenty-two which itself currently produce and supplies more than 1340 MMSCFD of natural gas which is almost 50% of whole country capacity. It also produces 9500 BPD of condensate. Studied Gas plant is situated at 150 km northeast of Dhaka. The details are in Appendix A: Petro Bangla Production report.

4.2.1 Studied Gas Plant Process Description

Studied Gas Processing Plant is divided into two zones: North zone and South Zone. The north zone is facilitated with 7 operating wells and 5 future connection wells whereas the south zone is facilitated with 5 operating wells along with 7 future connection wells. A 3.9km 20inch gathering pipeline connects the north zone with production header of south zone which is then tied into a single sectionalized inlet header upstream of the high-pressure inlet separators. The natural gas processing plant mainly consists of:

4.2.2 High Pressure Separation

The hydrocarbon (HC) gas, condensate and water flows from the North and South well zones, at a pressure of 1265 psig and a temperature of 95°F, through the inlet gas manifold and into four production trains which have a capacity of about 200 MMSCFD each although at initial stage the design value was 150 MMSCFD. Later, the separators were modified to give a higher capacity. The high-pressure separator consists of two compartments for water and condensate respectively, separated by a weir. The inlet stream flows through an even-flow inlet device, mesh type mist agglomerator and spiral-flow cyclone to give a better separation.

The condensate downstream is passed through high pressure and low-pressure flash tanks consecutively. The gas outlets from these two tanks are sent to vapor recovery unit. The liquid outlet is stored to condensate storage tank.

The water downstream from the HP separator is flashed at 25 psig in Low pressure Boot. The downstream water from the LP Boot is stored in dirty water tank. The processed water is then passed to clean water tank through an overhead tube. This clean water is injected back to the well.

The gas outlet from the HP separator enters the gas dehydration system through a filter coalesce to remove any residual liquids and solid particles.

4.2.3 Gas Dehydration System

The gas outlet from each separator flows into the tri-ethylene glycol (TEG) contactor where the gas is dehydrated to an outlet specification of 5 lbs./MMSCF water using TEG in a conventional counter-current flow contactor tower with structured packing. The outlet gas from the contactor with specified water content is then sent to the sales metering station.

4.2.4 TEG Regeneration System

Rich TEG from each contactor is processed in separate regeneration skid. TEG regeneration is done by means of a direct gas-fired re-boiler. The TEG regeneration process involves passing the Rich Glycol through the still column to gain some heat before entering the flash drum. In the flash drum the condensate remaining in the rich glycol gets separated. The Glycol is then passed through particle filters to remove particulates and charcoal filter to remove dissolved hydrocarbons. The Rich Glycol is heated in a cross exchanger to preheat the feed to the Still Column where the Glycol present in the water vapor leaving the re-boiler is recovered. Any carryover of TEG is collected in a boot at the low point of the common sales header and sent to the Glycol Sump where it can be recycled to the process [26].

4.2.5 Vapor Recovery unit

The VRU consists of a three-stage reciprocating Vapor Recovery Compressor that compresses hydrocarbon vapors flashing during the depressurizing of the high-pressure condensate and water. The vapors are compressed back to1235 psig to be recycled to the Inlet Gas Manifold. The total design capacity of the VRU is 1.7MMSCFD, but the first stage only handles 0.16 MMSCFD with the remaining gas entering the second stage suction. Each stage has a Suction Scrubber to ensure a dry gas feed, a reciprocating compressor stage (with suction and discharge pulsation dampeners), and a discharge cooler.

Vapors from the two LP Gas Boots and the two LP Separators are combined in a common first stage suction header. This suction header pressure is controlled at 25 psig by a pressure control valve that spills gas back from the first stage discharge. The first stage compresses the hydrocarbon vapors to 95 psig before being cooled to 110 °F in the First Stage Discharge Cooler. Vapors that flash from the Flash Gas Separators (in excess of rich fuel gas requirements) are combined with the discharge of the first stage and compressed to 413 psig in the VRU second stage. The second stage discharge is cooled and then compressed to 1235 psig in the third stage. Some of the third stage discharge is spilled back to the second stage suction to maintain the second stage suction at 90 psig [27].

4.2.6 Flare system

Flare system is a common safety system used in gas processing plants. The flare system not only protects the units from being over pressured but also can burn the extra gas in emergency. In the studied gas field there are two flare system named as HP and LP flare system. Pressure relief valves; blow down valves and manual vent valves on the HP systems discharge into the HP flare header. Any liquid accumulated in the HP knockout flare drum is pumped to the LP flare knockout drum using HP flare drum pump. The HP flare capacity is 300 MMSCFD. In emergency situation all the gas captured in the plant can be flown through blow down valves to the flare for burning. The LP flare takes inlet from condensate tank and closed drain header. The liquid from the LP knockout drum is pumped to the oily water drain tank.

4.2.7 Gas liquid Separation

The basic equipment for separating liquid from vapor uses both gravitational and centrifugal force. The gravitational force is used by reducing velocity so that the liquid can settle out in the space provided. Centrifugal force is used by changing the direction of flow. A true separator depends on the gravitational force to a substantial degree and has sufficient liquid retention time to allow for effective vapor-liquid disengagement.

As the Efficient separation of vapor and liquid is a critical processing operation, a complete separator must have the following characteristics;

- A primary separation section to remove the bulk of the liquid from the gas
- Sufficient liquid capacity to handle surges of liquid & to adequately degas the liquid
- Sufficient diameter & length (height) to allow the small droplets to settle out by gravity (to prevent undue entrainment.)
- A means of reducing turbulence in the main body of the separator so that proper settling may take place
- A mist extractor to capture entrained droplets & those too small to settle by gravity
- An inlet device to absorb the momentum (kinetic energy) of the entering fluid

- Vortex breaker on liquid outlet nozzle
- A method of solids removal, e.g. sand jets
- Manways or hand –holes to access the vessel for inspection & cleaning
- Proper pressure & level controls, alarms & shutdowns.

Separators can be categorized into three basic types; vertical, horizontal and spherical. Selection of a particular type depends upon the application and the economics.

Horizontal Separator may be of a single-tube or a double –tube design. A horizontal separator is mostly used because of the following advantages;

- They have a much greater gas- liquid interface area, permitting higher gas velocities. Therefore, they can handle large gas volumes economically and efficiently.
- They are cheaper to fabricate and ship than vertical separators.
- They are also easier and cheaper to install and service.
- They minimize turbulence and foaming.
- For a given capacity, horizontal separators are smaller and cheaper than vertical separators.
- They are usually used for high GOR wells, for foaming well streams and for liquid–liquid separations [28].

4.2.8 Tri-ethylene glycol

Tri-ethylene glycol (TEG) is the most frequently used glycol for natural gas dehydration due to

- its higher thermal stability and lower vapor pressure
- it could be easily regenerated to high concentrations at atmospheric pressure
- its ability to absorb large amounts of water
- relatively low solubility of valuable gas constituents
- chemical stability
- low cost

Physical and Chemical properties

(MSDS of Mallinckrodt Baker Inc. Philipsburg Nz 08865)

Appearance: Clear, colorless liquid.

Odor: Odorless.

Solubility: Miscible in water.

Specific Gravity: 1.1274 @ 15C/4C

pH: 7.28-7.47

Boiling Point: 285C (545F)

Melting Point: -5C (23F)

Vapor Density (Air=1):5.17

Vapor Pressure (mm Hg) < 0.01 @ 20C (68F)

Composition

Tri-ethylene glycol > 95%

Ethylene glycol >0.1%

Diethylene glycol 4.2%

Tetra ethylene glycol 1.8%

Lean TEG: pH 7.28-7.47

Water content 0.87-1.55%

Rich TEG: pH 6-6.5

Water content 5.99-11.97%

The TEG should be clear; it can be colorless, yellow or brown. A black and turbid TEG could lead to problems. Thermal degradation of the glycol can lead to foaming and corrosion damage. When glycols are thermally degraded, carboxylic acids are produced, which leads to a decrease in pH. If a second layer is present on top of the glycol, then the hydrocarbon content is too high. This can lead to stable foam. Heavier hydrocarbons can be enriched in the TEG from either the natural gas feed itself, or through leakage of machine oil contaminating the TEG.

4.3 Challenge Identification

When produces from reservoir, natural gas contains large amount of water particles. This water particles accumulate in pipeline and cause pipeline capacity reduction. They also result hydrate formation which plug the pipelines. Their corrosive effect damage pipelines too [29]. Hence, Ethylene glycols are commonly used in natural gas hydration and treating applications to remove water and impurities. Di-ethylene glycol (DEG), Tri-ethylene glycol (TEG) and Tetra-ethylene glycol (TETRA EG) have excellent hygroscopicity and low volatility. Because of these characteristics, DEG, TEG and TETRA EG are in high demand in the natural gas drying market [30].

Ethylene glycols are commonly used as absorbent in natural gas dehydration to remove water whose success depends on lean tri-ethylene glycol (TEG) concentration. Injecting stripping gas into TEG re-boiler is effective way to improve this concentration [31].

However, high temperature at re-boiler still column outlet leads to higher glycol loss. Any measures to stabilize this temperature will minimize this TEG loss. Impurities in glycol solution promote foaming in dehydration column. So, Carbon filters are incorporated in glycol circulating systems to remove dissolved impurities such as compressor oil or condensate [32].

Due to oil market downturn most of IOCs facing challenges to their existence. Hence, any sustainable cost reduction attempt is very convivial now a days. Lean approaches for cost reduction have been massively practiced in batch processing like automobile manufacturing industries (Toyota, Ford), in line manufacturing (Garments, pharmaceuticals industries) [33], discrete manufacturing (aircraft industry) and medical technologies (Oncology). But studies are hardly found which dealt with this approach in continuous production process like upstream natural gas processing industry. Lean approach with the integration of six sigma methodology through DMAIC model will be applied in natural gas processing industry aiming towards establishing sustainable cost reduction in this study.

4.4 Why choosing Lean six sigma and DMAIC

As discussed in literature review section; among fundamentally five rudimentary steps which are essential to reduce cost, only elimination of waste and improving operations are suited to natural gas dehydration plant. Based on the discussion of thirteen tools and strategies of cost reduction, it is presumed that these two functions perfectly fit to Lean Six Sigma process. Moreover; Lean six sigma assures sustainability of achieved cost reduction.

In this case studied project selection tree has been used to chose DMAIC. From the segment 4.3 Challenge identification, it is found that this project will require to Implement complex changes to a process like absorbent TEG flow rate change, charcoal filter replacing frequency change etc. This project will also require including several functions to change reality and multifunctional group engagement require to run project like Production department for implementing changes to process, Laboratory department for lab analysis, Facility Engineering Department for validating the improvements and HES department for ensuring process safety during project running. Therefore, DMAIC was selected to run the project as it complies to the guidelines of project selection tree.

Table 4.1: Studied Lean six Sigma Projects selection tree

If need to	If need to	If need to	If need to
-Evaluate a relatively new process -Baseline a process -Establish process controls -Understand a process from a high level -Identify & prioritize improvements	-Implement complex changes to a process -Include several functions to change reality -Multifunctional group engagement requires to run project	-Improve a specific portion of a value stream -Analyze an issue raised by customer requirements -Support a CPDEP phase	-Quickly fix a single element within a process -Implement an obvious solution -Implement a change that will quickly impact -something critical to the customer
Do a Value Stream Mapping	Use DMAIC	Do a Kaizen	Do a SALSSA

CHAPTER 5

DATA COLLECTION, IMPLEMENTATION AND RESULTS ANALYSIS

5.1 Introduction

This project has been completed in two phases. A total number of 03 (three) cases were modeled. Time line and target of lean six sigma in each phase is summarized below which incorporates change in a natural gas plant's Charcoal filter consumption, varying absorbent (Tri-ethylene glycol) flow rate and tuning Re-boiler still column temperature.

Table 5.1: Distribution of two Phases in studied Lean Six Sigma project

Phase	Case	Target
1	1	TEG loss reduction from Dehydration System by TEG flow rate reduction
	2	Charcoal Filter consumption reduction from Gas Dehydration System
2	1	TEG loss reduction by Re-boiler still column temp. fluctuation reduction

5.2 Lean six sigma Phase-1

Scope of Lean in Phase-1 of this project was Charcoal filter cost & TEG consumption.

5.2.1 Phase 1 "DEFINE" step: Developing EIS (Executive Improvement Summary)

At the first step the problem background was defined by selecting particular problem for resolution depending on VOC (Voice of customer). Also, the magnitude of the problem, process location, and the problem's impact on the business by using *"As is-To Be"* Process map.

Table 5.2: EIS (Executive Improvement Summary) of phase-1 case-1

Scope of Lean: TEG consumption

As per TEG fill up log; train 1 to 4 TEG consumption is higher than Train 5-6. If train 1 to 4 TEG consumption could be reduced–have opportunities to reduce the OPEX.

The Way We Are doing It

TEG circulating pumps of Trains-1 to 6 runs at its full flow rate capacity at 32 GPM regardless the actual amount of TEG required to dehydrate the gas

The Way We Will Do It

Reduce pure TEG circulation flow rate to 20 GPM in Train-1 to 4 until hampering dehydration process performance

Table 5.3: EIS (Executive Improvement Summary) of phase-1 case-2

Scope of Lean: Charcoal filter cost

Trains 1 to 4 contain charcoal filter. If train 1 to 4 could be operated without charcoal filter, there will be opportunities to reduce the operational cost.

The Way We Are doing it

Train 1-4 Charcoal filter change interval is time based (30 days) as per process control narrative

The Way We Will Do It

- Increase the charcoal filter change interval to 60 days
- Trial run of Low-cost filter ($92 USD/each) RIK instead of present one($258/each)
- Check purity & HC content of TEG to sustain change

5.2.2 Phase 1 "Measure" step: Current state mapping of case -1

The second step is to measure the current condition by detailing the specifics of the current-state process and measuring what is the problem and where is the problem. Also, it is required to determine process capability and review baseline performance with set target. Here Pie chart and bar chart has been used to determine process capability and review baseline performance with set target.

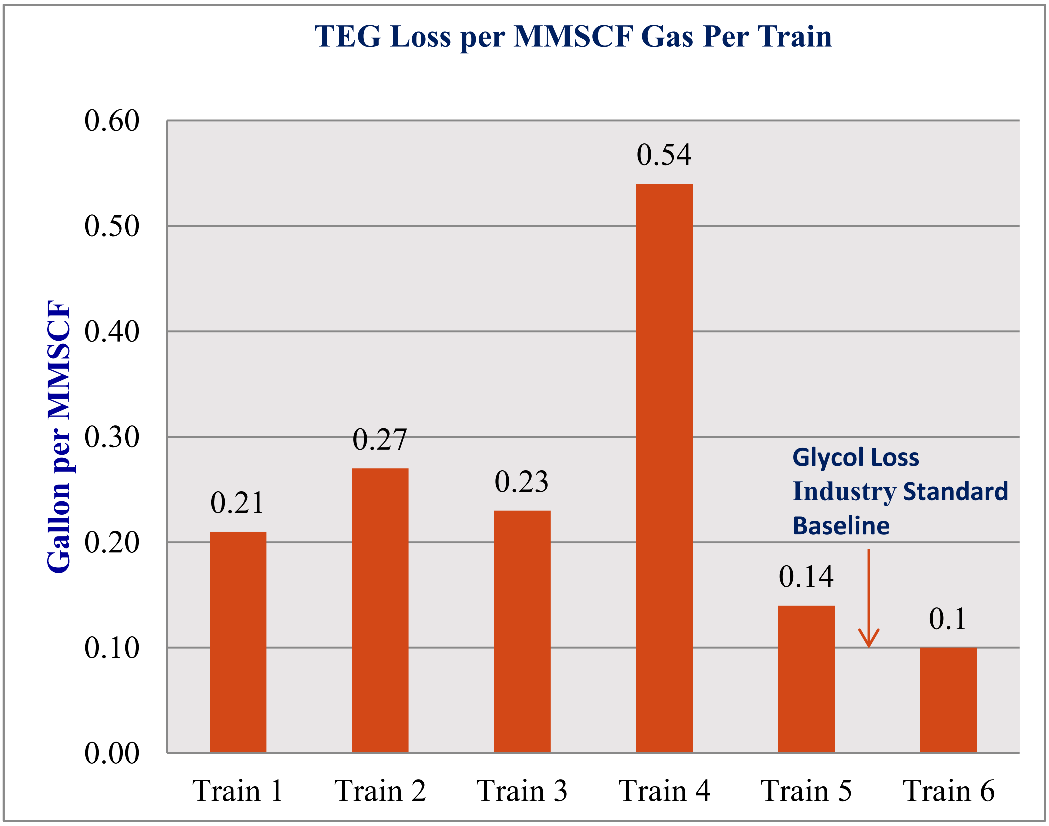

Fig 5.1: Absorbent (TEG) loss per MMSCF Gas per train

- According to studied plant's Dehydration Manual section 2.1.4: excessive glycol losses >0.1 Gallon/MMSCF
- Glycol loss in Train #1, 2, 3 and 4 does not meet industry standard.
- Train #4 is the worst contributing train of TEG loss.
- TEG loss has been calculated based on TEG Level drops in Accumulator and TEG volume added by OPS for specified period.

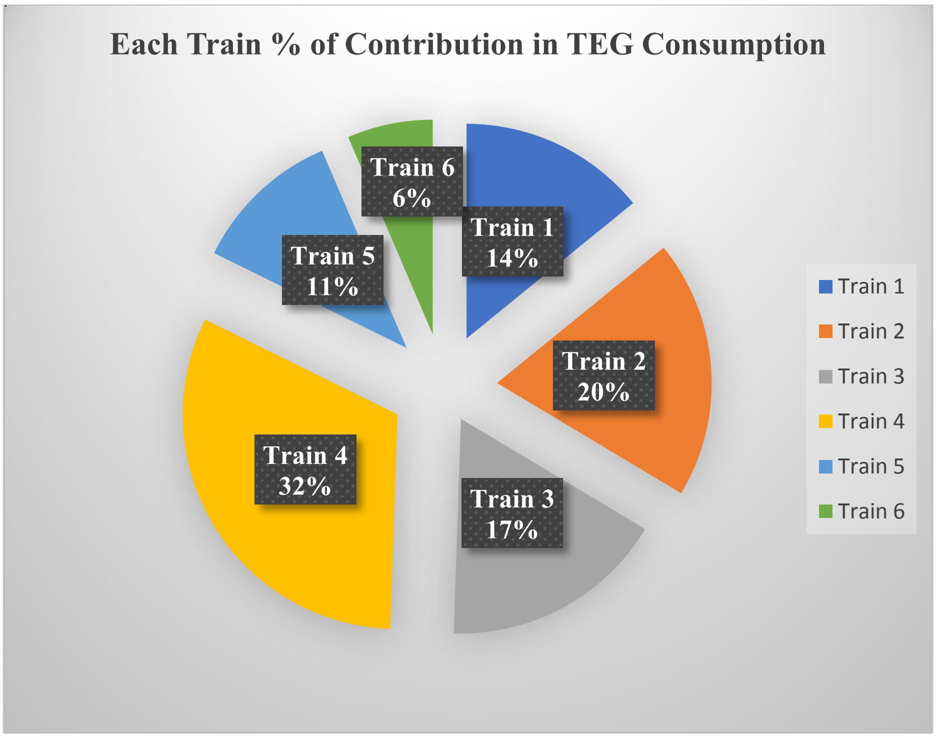

Fig 5.2: Each train percentage of contribution in Absorbent (TEG) loss / consumption

5.2.3 Phase 1 case-1 "ANALYZE" step: Correlation analysis in PI software

The third step is to analyze whether the taken steps work or not by using data and evidence in a thorough and objective review. Also, it is required to validate the course of actions performance and effectiveness. It is must to document all solutions to solve these causes.

Here, two step TEG flow rate reduction has been done and data has been pulled out from PI Software to analyze whether gas dehydration performance degrade or remain same. As per studied plant's operation control narrative [13] TEG circulation rate to be maintained in each train is 32 Gallon per minute. This rate was reduced to 25 GPM and data analyzed for six days. In the next step TEG flow rate was reduced to 20 GPM and data analyzed for 15 days. TEG loss per day was reduced in both case and moisture content in gas was within limit. Desired limit is < 1.00 lbs./MMSCF moisture content as per production business target. Therefore, the reduced rate can be sustained for further which will be very cost effective.

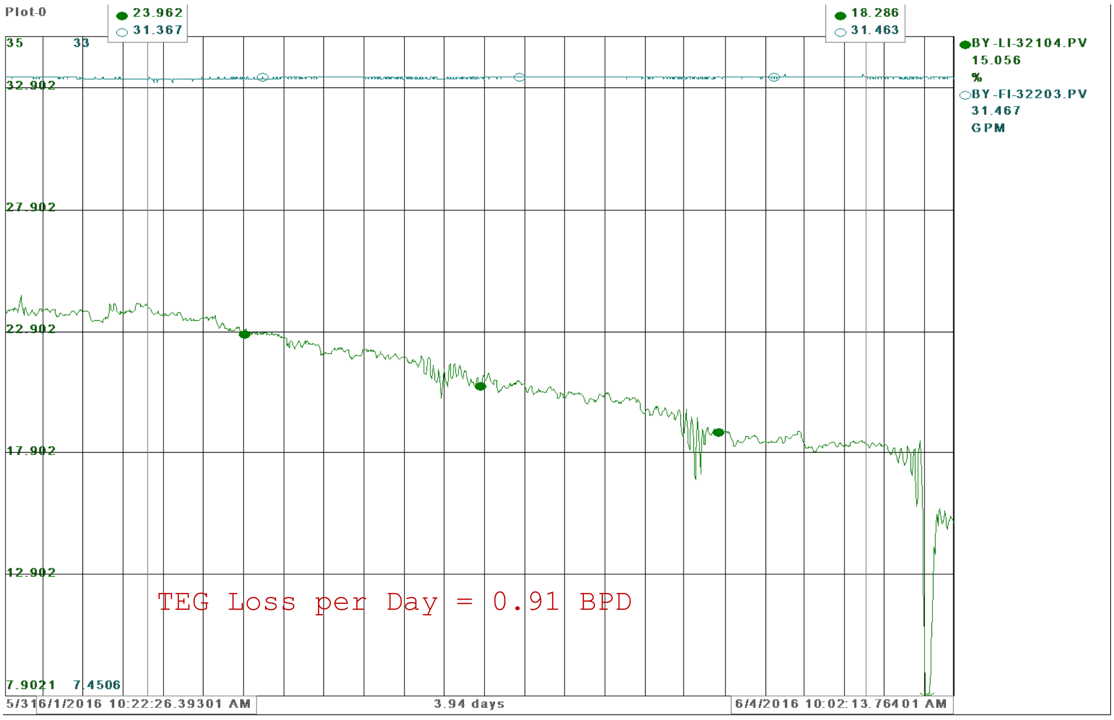

Fig 5.3: PI Software data analysis: Test Sample – 1: Train-2: Lean TEG Flow Rate 32 GPM

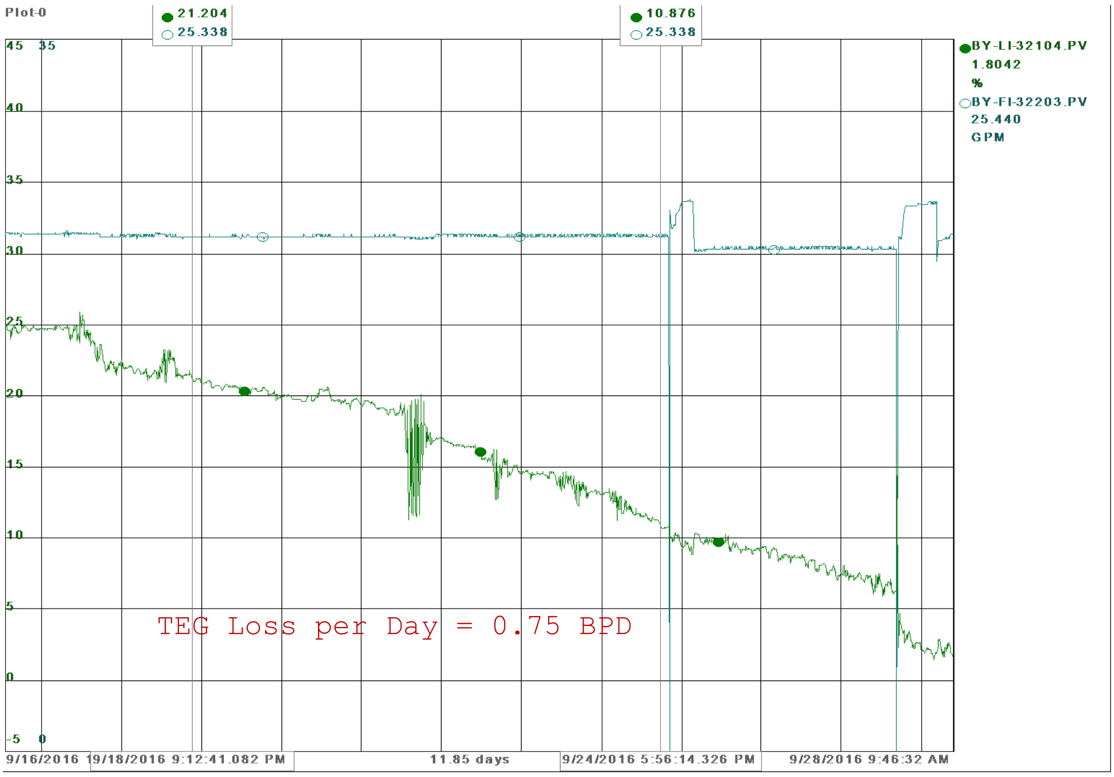

Fig 5.4: PI Software data analysis: Test Sample – 2: Train-2: Lean TEG Flow Rate 25 GPM

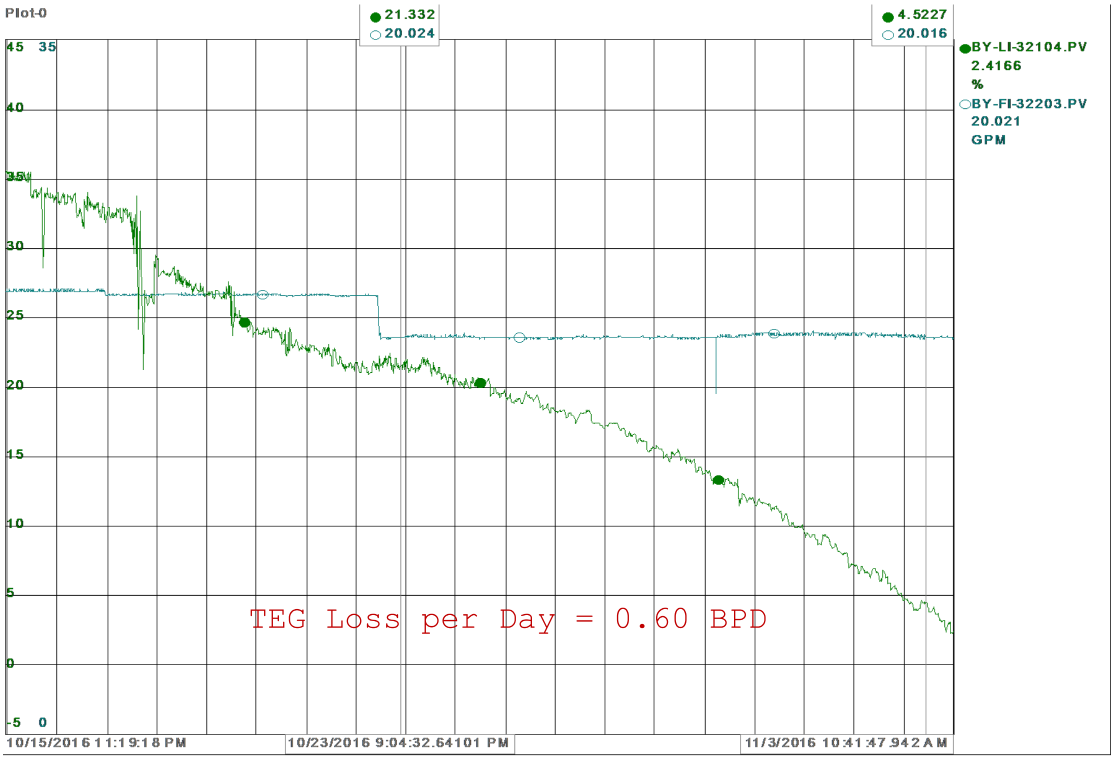

Fig 5.5: PI Software data analysis: Test Sample – 3: Train-2: Lean TEG Flow Rate 20 GPM

In this study baseline performance target was declared moisture content limit < 1.00 lbs./MMSCF as per production business target. Train-2 was selected for the experiment. After reducing TEG flow rate in two steps the baseline performance target was fulfilled. So, the other critical process parameters related to absorbent flow rate was analyzed.

Table 5.4: Train-2 Dehydration Performance Comparison after Lean six sigma

Process Parameter	**Before LSS**	**After LSS**
TEG Circulation Flow Rate, GPM	32	20
Gas Flow Rate, MMSCFD	205	205
Train 2 Dew Point at sales line, lbs./MMSCF (dehydration performance)	0.86	0.95
Average TEG consumption Gallon/MMSCF (Based on level drop in Accumulator)	0.28	0.18

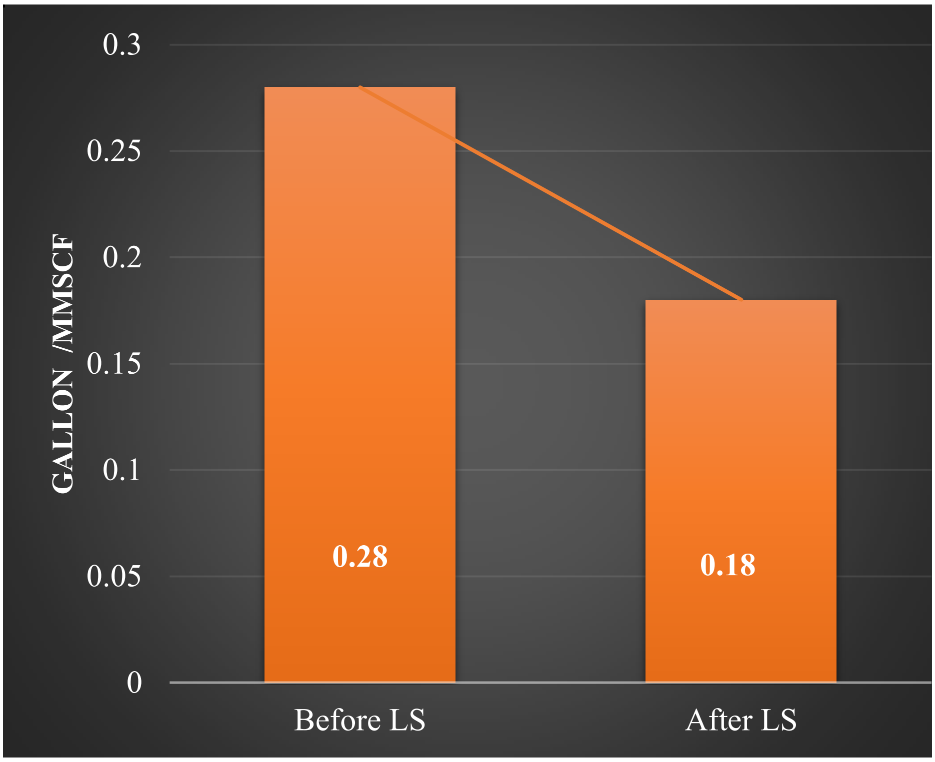

Fig 5.6: Train-2 TEG consumption improvement after lean approach

5.2.3.1 Key findings in Phase-1 case-1 "ANALYZE" step

- No impact on dehydration performance or no process upset in Train #1, 2 and 4 at 20 GPM Lean TEG flow rate.
- Dew point of Train #3 increases when the TEG flow rate is reduced at 27 GPM.

5.2.3.2 Key decisions in Phase-1 case-1 "ANALYZE" step

- Train #1, 2 and 4 is maintaining 20 GPM Lean TEG Flow rate.
- Train #3 TEG flow rate has been kept at 30 GPM.

5.2.3.3 TEG Consumption Before and after Lean approach

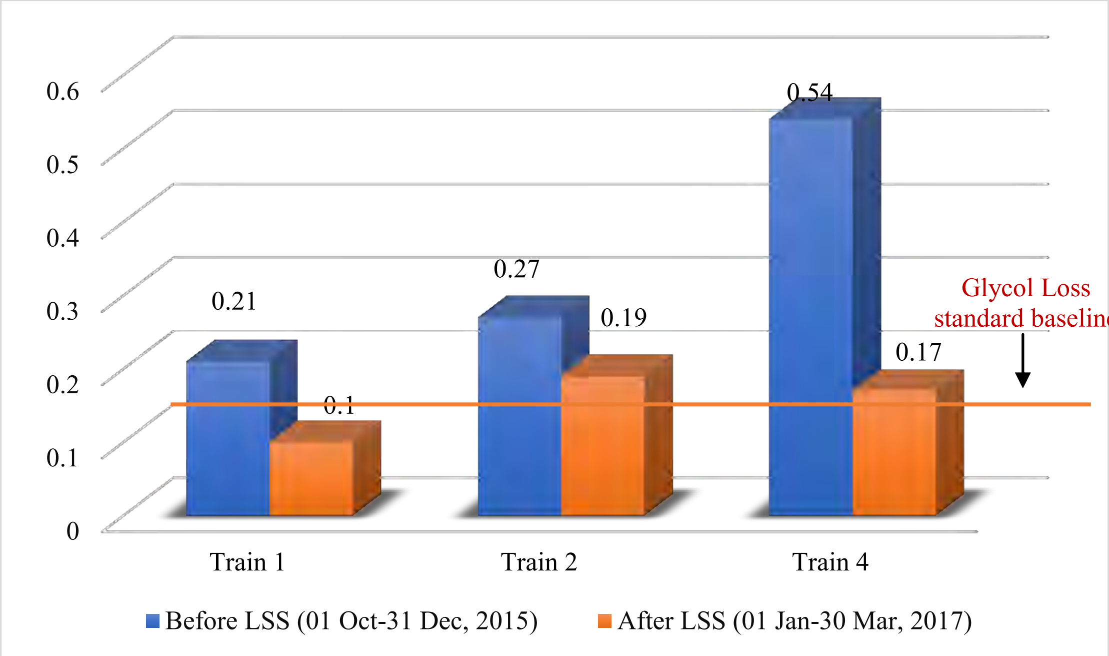

Fig 5.7: Train 1-4 Dehydration Performance Comparison before and after LSS

5.2.3.4 Phase-1 case-2 "ANALYZE": Cost Data Analysis

Table 5.5: Phase-1 case-2 Cost data analysis after Lean approach

Subject	Comparison Yearly		Hard Save ($)/year (AFB)	Comments
	Before project Filter Change Interval 30 days	After Project Filter Change interval 60 days		
Filter Required/year	480	240		
Total Price with filter($258/each)	$ 1,24,099	$ 62,049	$ 62,049	Present benefit after 3 months
Introduce low cost filter RIK ($92USD/each)	$ 1,24,099	$ 22,080	$ 1,02,019	After Validated with MOC process & lab analysis

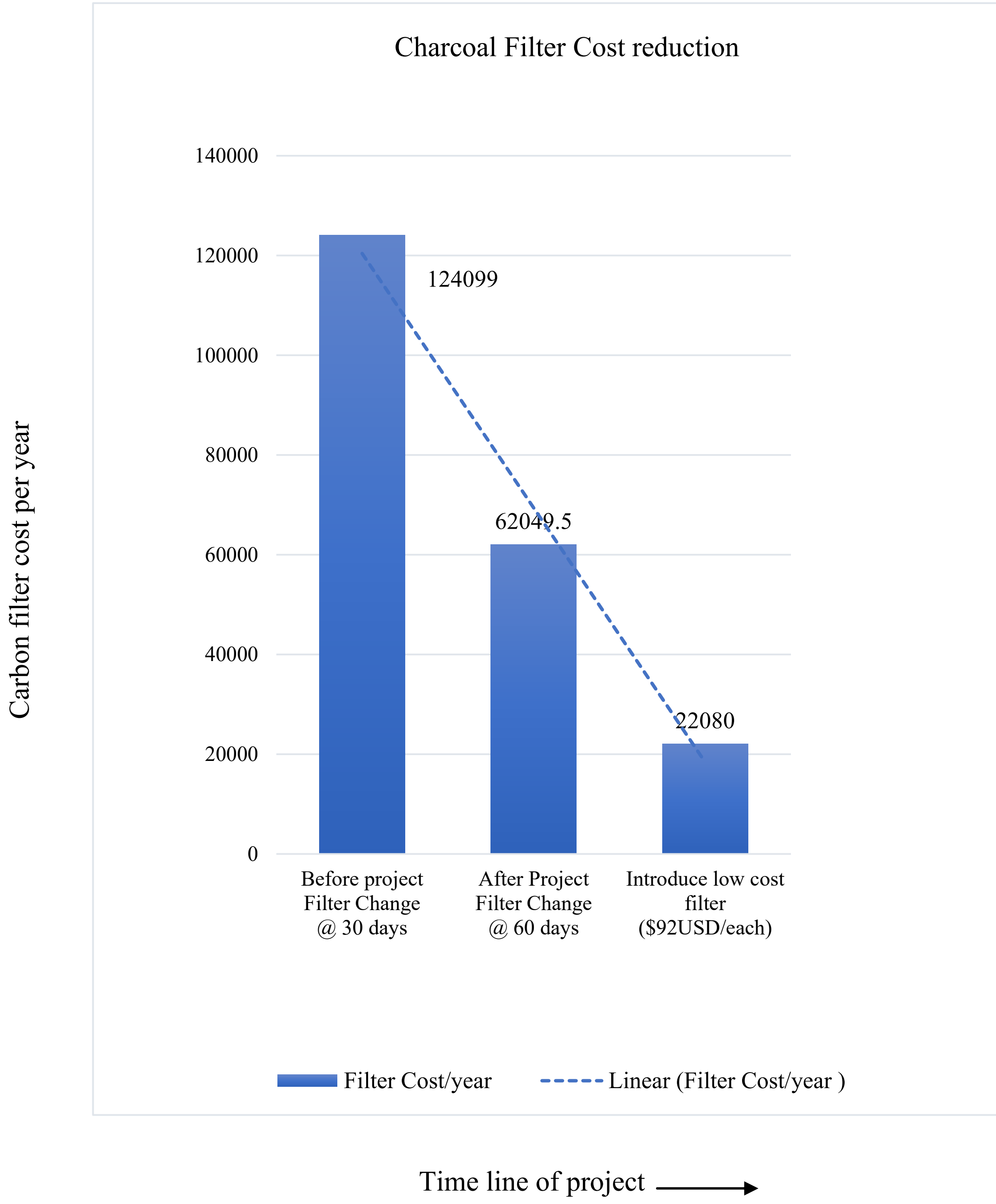

Fig 5.8: Charcoal filter cost analysis after lean approach

5.2.4 Phase-1 "IMPROVEMENT" step

The fourth step in DMAIC is to determine magnitude of improvement by evaluating financial gains. Also, it is required to calculate the success of taken lean steps by COPQ (Cost of poor quality) or cost benefit analysis. Therefore; COPQ has been calculated.

5.2.4.1 Phase-1 case-1 "IMPROVEMENT" step: COPQ calculation

Table 5.6: Phase-1 case-1 COPQ calculation for TEG loss reduction

Description (Unit)	Train 1	Train 2	Train 4
% of TEG Loss Recovery	53.60%	32.93%	67.78%
TEG Loss Recovery (Bbl. /year)	165	120	247
Hard Benefit ($ / Year)	41623	30232	62229
Project Benefit from LSS on TEG Consumption in Train #1, 2 and 4 ($ / Year)	**134K**		

5.2.4.2 Phase-1 case-2 "IMPROVEMENT" step: COPQ calculation

Table 5.7: Phase-1 case-2 COPQ calculation for Charcoal filter cost reduction

Saving type	Improved Parameters	Amount Saved (USD)
Hard	TEG Loss Reduction	18125
Soft	Man-hour filter change	4464
Hard	Waste Disposal save from TEG	3719
Hard	Waste disposal Charcoal	1400
Soft	Waste management man-hour	5758
Hard	Transportation of Waste to Lafarge	515.95
	Total Associated cost save	**33466**

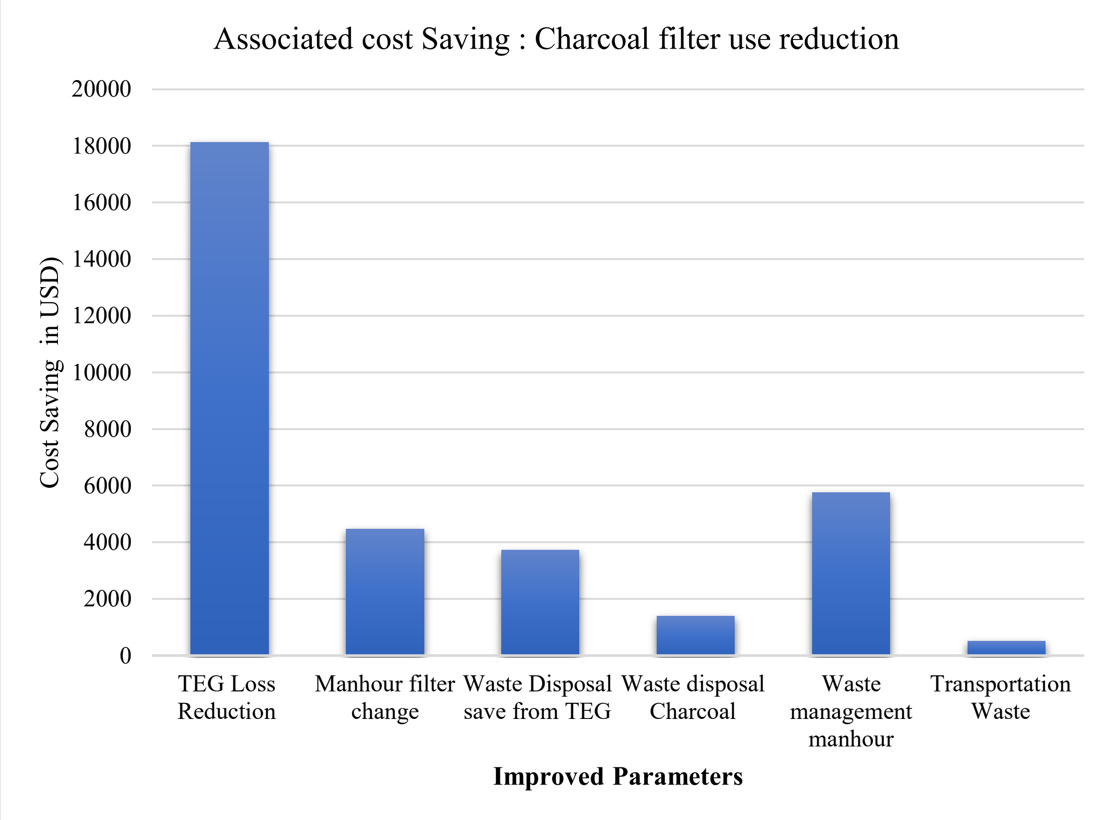

Fig 5.9: Phase-1 case-2 COPQ calculation for Charcoal filter cost reduction

5.2.4.3 Phase-1 case-2 "IMPROVEMENT" step: AFB calculation

Table 5.8: Phase-1 case-2 AFB (Accrued Financial Benefit)

Filter cost saving	1,02,019
Associated Cost Saving	33,466
Total AFB ($)	$1,35,485

5.2.5 Phase-1 "CONTROL" step: Action plan and PICK chart development

The fifth step is to control the improvement result and follow up for sustainability. It is required to deploy the infrastructure for sustaining the gains (such as standardization, audits, dashboards and reviews) and share findings across the organization/enterprise as appropriate.

Result/Decisions

- Train #1, 2 and 4 is maintaining 20 GPM Lean TEG Flow rate.

- Train #3 TEG flow rate has been kept at 30 GPM.
- Charcoal filter change frequency maintain 60 days.

Table 5.9: Phase-1 "CONTROL" step: PICK Chart development (Possible, Implement, Challenge, Kill)

<table>
<tr><th colspan="4">To do list</th><th colspan="3">Resources/Challenges</th><th>PICK</th></tr>
<tr><td colspan="4">Filter housing TEG divert to reboiler to save TEG going to sump</td><td colspan="3">MOC approval, engineering calculations on design and piping, piping and installation cost.</td><td>K</td></tr>
<tr><td colspan="4">Reduce the TEG flow rate further down from 20 GPM without affecting dehydration system in Train #1, 2 and 4.</td><td colspan="3">Management approval, Manpower engagement, Lab Analysis, Long time, Sales gas moisture increase</td><td>K</td></tr>
<tr><td colspan="4">Same TEG consumption reduction study can be applied in Train #5 and #6 to get better performance.</td><td colspan="3">Management approval, Manpower engagement, Lab Analysis, Long time,</td><td>C</td></tr>
<tr><td colspan="4">Dig down the causes making Train #3 unable to operate below 27 GPM TEG flow rate, rectify the problems and perform the same TEG consumption reduction study in Train #3.</td><td colspan="3">Management approval, Manpower engagement, Lab Analysis, Long time, Sales gas moisture increase</td><td>C</td></tr>
<tr><td colspan="4">Glycol Sump tank blanketing with nitrogen or fuel gas</td><td colspan="3">Require engineering calculations on design, piping and sourcing gas.
Add more cost</td><td>K</td></tr>
<tr><td colspan="4">Train 1 to 4 Re-boiler still column temperature is higher than set point 212 °F (Water boiling point) causing TEG vapor to atmosphere</td><td colspan="3">Analysis TV-3X605 performance trend in PI software and go for either set point change in HIS or PID tuning</td><td>I</td></tr>
<tr><td>P</td><td>Low effort

Low benefit</td><td>I</td><td>Low effort

High benefit</td><td>C</td><td>High effort

High benefit</td><td>K</td><td>High effort

Low benefit</td></tr>
</table>

5.3 Lean six sigma Phase-2

In the PICK chart of Phase-1 lean six sigma one CONTROL action was found to "Implement". Therefore; scope of Lean in Phase-2 of this project was reduction of

TEG Loss through still/column by analyzing TV-3X605 performance trend in PI software and go for either set point change in HIS or PID tuning.

5.3.1 Phase-2 “DEFINE” step: Developing EIS (Executive Improvement Summary)

Similar to phase-1 *“As is-To Be”* Process map has been used to develop EIS of phase-2.

Table 5.10: EIS (Executive Improvement Summary) of phase-2

Scope of Lean: TEG Loss through still/column

Train 1 to 4 Re-boiler still column temperature is higher than setpoint 212 °F (Water boiling point) causing TEG vapor to atmosphere –Identify reason of not maintaining ~ 212 °F as per design and solve to reduce TEG loss

The Way We are doing It

Train 1-4 Glycol Still/Condenser outlet temperature set point in Temperature control valve, TCV-3X605 is 212 °F but monthly avg. >230 °F causing excessive reflux leading to TEG loss

The Way We Will Do It

Analysis TCV-3X605 performance trend in PI software and go for either set point change in HIS or PID tuning

5.3.2 Phase-2 “Measure” step: Current state mapping of TEG loss by Re-boiler still column temp. fluctuation

The second step of Phase-2 DMAIC is to measure the current condition by detailing the specifics of the current-state process and measuring what is the problem and where is the problem. Also, it is required to determine process capability and review baseline performance with set target. Here bar chart has been used to determine process capability and review baseline performance with set target. The average temperature of all Trains (Train-1 to 4) always found more than the set point 212 °F which is above water boiling point and causing loss of TEG through vaporization. S, baseline set performance is 212 °F.

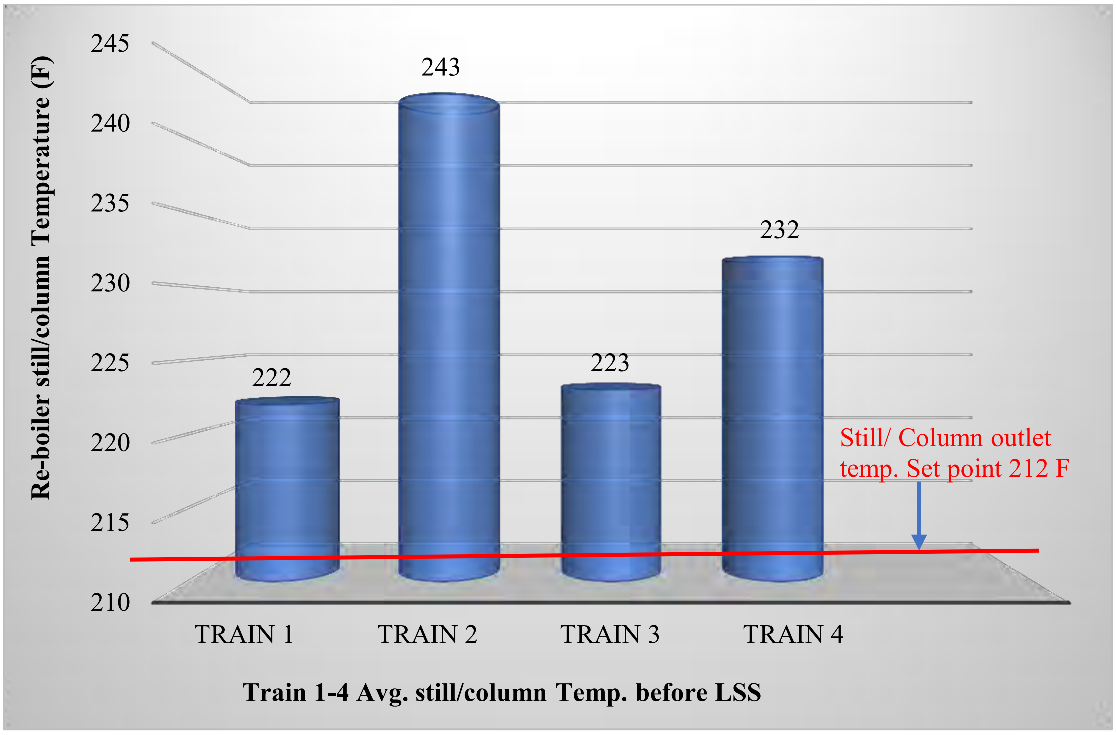

Fig 5.10: Phase-2 “MEASURE” step: Re-boiler still column avg. temperature comparison before LSS

5.3.3 Phase-2 “ANALYZE” step: Identifying DOD (Definition of defect)

The third step of Phase-2 DMAIC is to analyze whether the taken steps work or not by using data and evidence in a thorough and objective review. Also, it is required to validate the course of actions performance and effectiveness. It is must to document all solutions to solve these causes.

From PI software process trend, it is found that temperature control valve, TV-3X605 [X=1,2,3,4] is not providing steady control and thus resulting in continuous overshoot and undershoot in Glycol Still/Condenser temperature

This is resulting in high temp (223-240 ºF on daily average) at Glycol Still/Condenser outlet which is causing excessive reflux leading to glycol vapor.

Fig 5.11: Temperature control valve of Reboiler still column

5.3.3.1 Phase 2 "ANALYZE" step: Developing BOAT model (Barriers, Opportunities, Actions, Threats)

Table 5.11: BOAT model for phase-2 "ANALYZE" step

BARRIERS	OPPORTUNITIES	ACTIONS	THREATS
Temp is controlled in the outlet of Glycol Still/Condenser	Reduce set point of Glycol Still/Condenser outlet temperature in order to reduce outlet temperature	1. Reduce the set point of Glycol Still/Condenser from 212°F to 200 °F	Lowering set point below 212 F may retain water moisture in TEG leading to increase gas dew point
Glycol Still/Condenser temp control valve showing sinusoidal behave	Tune the P, I & D parameters of the controller	1. Changed the P, I & D parameters to identify the sweet spot. 2. Apply clamp in max opening of the control valve	Need Continuous monitoring by Control room Panel man on HIS

5.3.3.2 Phase 2 "ANALYZE" step: PID tuning

As per BOAT model action, the set point of Glycol Still/Condenser has been reduced from 212°F to 200 °F. P, I & D parameters has been tuned following Ziegler Nicholls method to identify the sweet spot. Clamp in max opening of the control valve has been set at 25% PV opening.

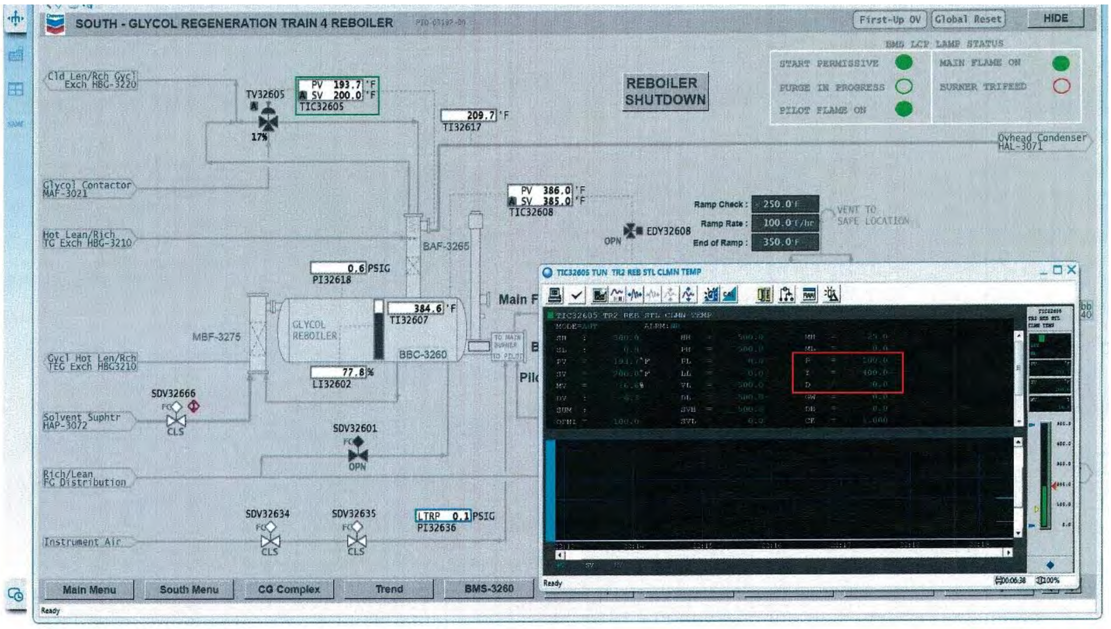

Fig 5.12: Train 4 Glycol Still/Condenser Temp. Control Valve TV-34605 PID controller tuning on control interface

For PID tuning in Ziegler Nicholls method following steps has been followed:

- All gains have been set to zero.
- The P gain has been increased until the response to a disturbance is steady oscillation.
- The D gain has been increased until the oscillations go away (i.e. it's critically damped).
- Steps 2 and 3 has been repeated until increasing the D gain does not stop the oscillations.
- P and D has been set to the last stable values.
- The I gain has been increased until it brings you to the setpoint with the number of oscillations desired.

5.3.3.3 Phase 2 “ANALYZE” step: Performance baseline comparison

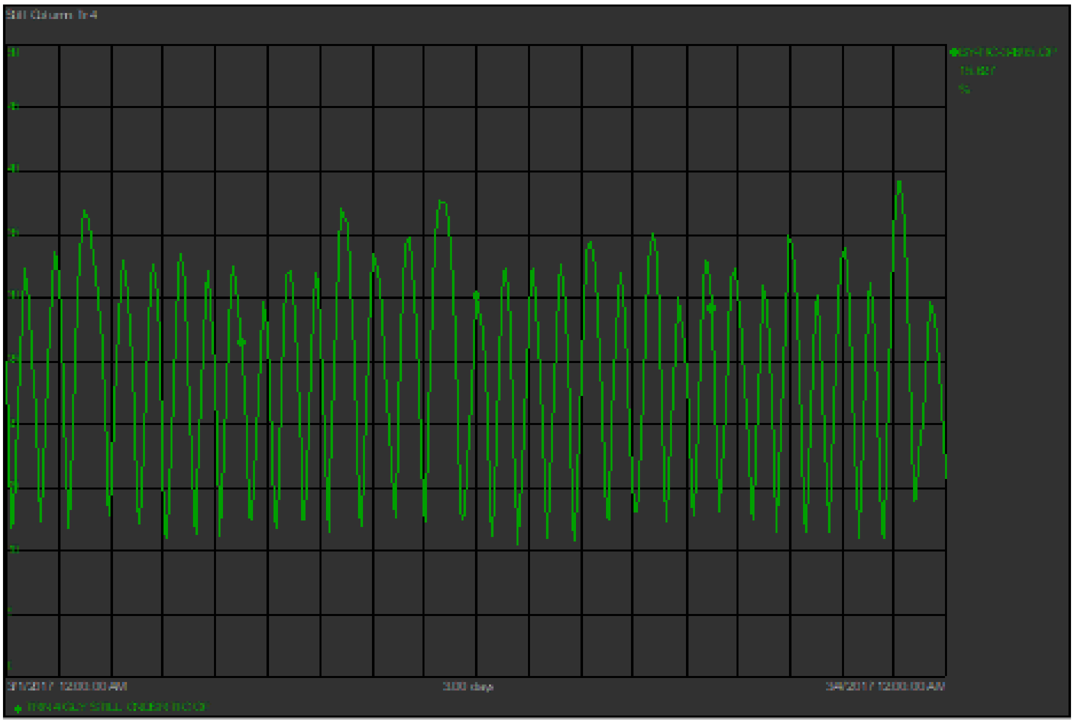

Fig 5.13: PI software analysis of Train 4 Glycol Still/Condenser Temp. Control Valve TV-34605 performance comparison before PID controller tuning

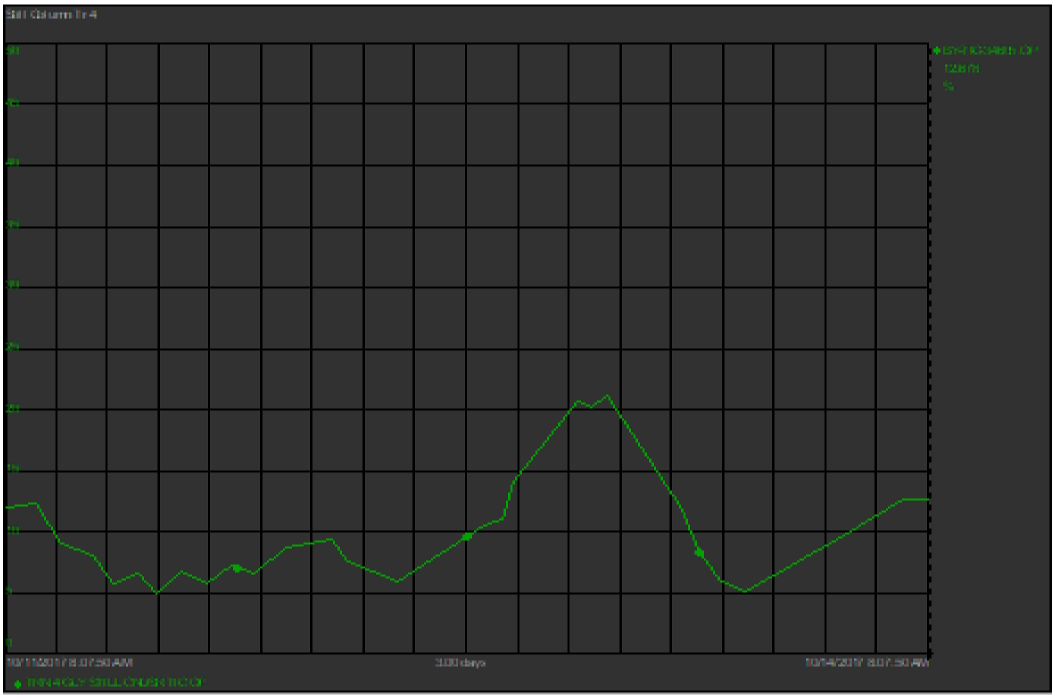

Fig 5.14: PI software analysis of Train 4 Glycol Still/Condenser Temp. Control Valve TV-34605 performance comparison after PID controller tuning

5.3.4 Phase-2 "IMPROVE" step: COPQ calculation

The fourth step in phase-2 DMAIC is to determine magnitude of improvement by evaluating financial gains. Also, it is required to calculate the success of taken lean steps by COPQ (Cost of poor quality) or cost benefit analysis. Therefore; COPQ has been calculated.

Table 5.12: Phase-2 "IMPROVE" step: COPQ calculation

Monthly TEG consumption in Train 1-4 BEFORE LSS phase-2	113.4 BBL
Monthly TEG consumption in Train 1-4 AFTER LSS phase-2	90.3 BBL
Less TEG consumption	23.1 BBL~ 18.3 DRUM
Price of TEG per drum	$ 290.57
Monthly savings	$ 5,323
AFB	**$63,880**

5.4 Results

Total sustainable cost reduction has been summarized here.

Table 5.13: Total results

Phase	Case	Target	AFB
1	1	TEG loss reduction from Dehydration System by TEG flow rate reduction	1,34,000 USD
	2	Charcoal Filter consumption reduction from Dehydration System	1,35,485 USD
2	1	TEG loss reduction by still column temp. fluctuation reduction	63,880 USD
Total AFB			**3,33,365 USD**

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

As absorbents and carbon filters are the basic materials which are to be outsourced in natural gas dehydration plant. Hence; focus of this project was in applying lean approach to these two materials.

A total number of 03 (three) cases were modeled in this project which includes TEG loss reduction from Dehydration System by absorbent (TEG) flow rate reduction, Charcoal Filter consumption reduction from Gas Dehydration System and TEG loss reduction by Re-boiler still column temperature fluctuation reduction. These three cases were coursed in two phases which evolves half of a production year.

First phase of this project was successful in terms of meeting target. Target of this phase was TEG loss reduction from Dehydration System by TEG flow rate reduction and Charcoal Filter consumption reduction from Dehydration System. 1,34,000 USD cost has been reduced by TEG loss reduction through TEG flow rate reduction. 1,35,485 USD cost has been reduced by Charcoal Filter consumption reduction. Hence; 1,35,485 USD was success of DMAIC utilization in phase-1 of this project in a calculated financial year.

Second phase of this project was also successful in terms of meeting target and aim. Target of this phase was TEG loss reduction from Dehydration System by still column temperature fluctuation reduction. 63,880 USD cost has been reduced by still column temperature fluctuation reduction. Hence; 63,880 USD was success of DMAIC in phase-2 of this project in a calculated financial year. Therefore; per year accrued financial benefit will be approximately equivalent to 0.33 million USD.

Hence, the primary target of cost reduction has been accomplished successfully. Moreover; using DMAIC tool to apply lean six sigma promises an assurance of sustainability of this cost saving.

As DMAIC tool is a structured application of both quality and statistical tools with the purpose of gaining process knowledge to make the output metrics safer, better and faster; natural gas dehydration process loop holes and defects also came out through this case study. Process conversance gained through this study will give more confidence to production team. Conglomerate will be able to realize tangible business value and to systematically improve existing processes. From this study; other natural gas plants of Bangladesh as well as of Asia, Africa and Arab basins can gain an understanding of lean six sigma process implementation and practices of sustainable cost reduction.

Some scopes of work could not be accomplished and left for future in this studied case. The action plans left in "Challenge section" of PICK chart of phase-1 "CONTROL" step can be started upon management approval. Same TEG consumption reduction study can be applied in Train-5 and Train-6 to get better performance and more cost reduction.

The causes can be dig down which are making Train-3 unable to operate below 27 GPM TEG flow rate Then the found causes can be rectified and the same TEG consumption reduction study can be performed in Train-3.

The TEG trapped into Filter housing is needed to drain out during Charcoal filter replacement. This TEG drain line can be diverted to re-boiler to save TEG going to sump. MOC approval, engineering calculations on design and piping, piping and installation cost can be taken in consideration if implementing this diversion.

If the above diversion is coming out as non-cost effective, Glycol Sump tank blanketing with nitrogen or fuel gas can be considered so that the drained out TEG will be usable then. Engineering calculations on design, piping and sourcing gas costing are needed to take in consideration in this case

6.2 Recommendations for future study

- The other tools of DMAIC such as Failure Mode & Effects Analysis (FMEA) can be used in natural gas dehydration cost reduction which will additionally evaluate the severity, occurrence and detection of risks and challenges to prioritize which ones are the most urgent. If between the two most popular types of FMEAs: PFMEA and DFMEA; Process Failure Mode & Effects Analysis is used in such studies that will also be able to rate the success in a scoring matrix with a 1-10 scale.

- VSM is more effective in evaluating a relatively new process. As sustainable cost reduction culture is relatively new in the oil and gas industry, Value Stream Map (VSM) can also be used to accomplish same pattern of study. It will also help to baseline a process, establish process controls, understand a process from a high level and Identify & prioritize improvements.

- Measurement System Analysis (MSA), Analysis of Variance (ANOVA), and OEE (Overall Equipment Effectiveness) can be utilized also for cost reduction and its sustainability in continuous production process like natural gas dehydration.

- In this study, validation of success has been taken forward to ensure sustainability of the achieved cost reduction. If there is time consistency or urgent basis requirements of cost reduction in natural gas dehydration plant, then validating the success of implementing changes can be skipped. Prioritization Matrix or Pugh Matrix can be exercised in such cases.

- Other lean approaches like bottleneck analysis, Hoshin Kanri and PDCA (Plan-Do-Check-Act) can be used in continuous production process like natural gas dehydration.

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Appendix A

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No: 41.01.09/2604.Dec.2014

Petrobangla

Production & Marketing Division

3, Kawran Bazar, Dhaka-1215

Date : 13-14 Aug, 2018 From 8.00 to 8.00

Units: Gas in MMCFD
Condensate/ NGL/ MS/ HSD in BBLD
LPG in Kg

Daily Gas & Condensate Production and Distribution Report

I. Production

Company	Gas Fields	No.of Producing Wells	Production Capacity	Production: Gas	Production: Condensate	Pro.as a % of T.Cap(Gas)	Pro.as a % of T. Prod(Gas)
1. BGFCL	Titas	26	542	525.2	452.0	19.1	19.1
	Habiganj	7	225	235.7	17.9	8.6	1.1
	Bakhrabad	6	43	29.1	14.0	1.1	1.0
	Narsingdi	2	30	27.0	42.7	1.0	1.0
	Meghna	1	11	12.2	23.6	0.4	0.4
	Sub-Total	42	851	829.2	550.2	30.2	30.1
2. SGFL	Sylhet	1	6	4.4	25.4	0.2	0.2
	Kailashtila #1 (Silicagel)	1	13	9.4	57.6	0.3	0.3
	Kailashtila #2 (MSTE)	3	55	51.8	463.5	1.9	1.9
	Rashidpur	5	60	52.4	48.7	1.9	1.9
	Beanibazar	2	15	8.9	134.5	0.3	0.3
	Sub-Total	12	149	126.8	729.6	4.6	4.6
3. BAPEX	Salda	1	3	4.6	2.0	0.2	0.2
	Fenchuganj	2	26	10.8	5.5	0.4	0.4
	Shahbazpur	3	50	43.0	7.5	1.6	1.6
	Semutung	2	3	1.2	0.0	0.0	0.0
	Sundalpur	1	5	6.8	0.1	0.2	0.2
	Srikail	3	40	32.4	87.7	1.2	1.2
	Begumganj	0	0	0.0	0.0	0.0	0.0
	Rupganj	0	8	0.0	0.0	0.0	0.0
	Sub-Total	12	135	98.8	102.8	3.6	3.6
	Sub-Total (1+2+3)	66	1135	1054.8	1382.6	38.4	38.3
4. IOCs							
CHEVRON	Jalalabad	7	270	242.7	1055.4	8.8	8.8
	Maulavibazar	6	42	32.3	3.3	1.2	1.2
	Bibiyana	26	1200	1341.0	9533.8	48.8	48.7
TULLOW	Bangora	5	103	82.8	244.0	3.0	3.0
	Sub-Total	44	1615	1698.8	10836.5	61.8	61.7
	Grand Total (1+2+3+4):	110	2750	2753.5	12219.1	100.1	100.0

III. RPGCL Production

Feed Received		Production		
NGL	Cond.	LPG	MS	HSD
515.8	0.0	17015	766.2	154.2

N-S & RA pipeline
Delivered from N-S pipeline

AB1	304.9
AB2	265.6
BB	274.1
VS3	133.9
AM	227.1
BD	491.6
Total	1697.2

Remarks:

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Appendix B

Lean Six Sigma Project Mentoring Guide						-
-	<u>Step Number</u>	<u>Questions:</u>	<u>Deliverables</u>	<u>Date Complete</u>	<u>Recommended Tools</u>	<u>Comments</u>
Define	1	Who are your customers for the assigned project? What is the business case? What are the deliverables for the project? What Metrics to Capture?	SIPOC		**SIPOC**	
			Project Contract		**Project Contract**	
			Primary and Secondary Metrics VOC/VOB		QFD, Customer Interview	
	2	What are the major steps in the process? Does the project need to be scoped?	Macro Process Flow		Flow Chart	
			Scope of Project / Boundaries Potential Project Spins Offs into the Project Queue		Cascading IPO	
	3	How have you prioritized improvement opportunities? Who are the stakeholders in the process? Who are the team members working on these improvements? What are the goals and timeline for the project? Is this an opportunity for a Kaizen?	Identify and Prioritize Opportunities		**Pareto Charts, FMEA**	
			Stakeholder Analysis		Stakeholder Analysis	
			Project Contract / Signature Page		**Project Contract / Signature Page**	
			Project Plan or Kaizen Plan		Gantt Chart, Kaizen Plan	
	Measure:	<u>Questions:</u>	<u>Deliverables</u>	<u>Date Complete</u>	<u>Recommended Tools</u>	<u>Comments</u>
Measure	4	What is the current state of the process? Is the process constrained?	Current State Map		Process Flow Diagram, Value Stream Map, Physical flow map, Constraint Map, OEE.	
	5	How is the process measured? Is the measurement precise? Accurate?	Assessment of Measurement System		Measurement System Analysis	
	6	What is the baseline for the key performance metrics? What are the specifications of the process? Is it capable?	Process Baseline		Data Collection, Histogram, **Run Charts**, Control Charts, **Box Plot**, OEE	
			Process Capability		Capability Study (Product Capability, Cap Charts), Customer Interview	
	7	What is the Cost of Poor Quality?	COPQ		Cap, dpmo, cost data	

Lean Six Sigma Project Mentoring Guide (continued)						
	Steps	Questions:	Deliverables	Date Complete	Recommended Tools	Comments
Analyze	8	What types of waste are apparent in the process? Are the primary metric(s) off-target. Does it exhibit high variation?	Prioritized list of 9 Classic Lean Wastes		Kaizen, Takt time, 5S, Process Flow Diagram, Value Stream Map, Physical flow map, Layout Design, OEE	
			Factors that move the mean or cause variation.		**Cause and Effect Diagram,** Pareto Chart, Regression, Control Charts, Pareto analysis, ANOVA, correlation analysis, DOE, t-tests, F-tests, Chi-Square tests	
	9	What are the sources of the problem? Root causes?	Root Causes of the Problem		FMEA, **5 Whys, Reality Tree,** Cause Mapping, OEE, Cause and Effect Diagram, Pareto Chart, Regression, Control Charts, Pareto analysis, ANOVA, correlation analysis, DOE, t-tests, F-tests, Chi-Square tests	
	10	What would a benchmark or "world class" process look like?	Project Goals		Customer Interview Form (VOC), Champion Interview (VOB), Benchmark study, Run Charts	
	Steps	Questions:	Deliverables	Date Complete	Recommended Tools	Comments
Improve	11	How can we remove the cause of the waste? How do the inputs to the process affect it? Do they interact?	Proposed Solutions		Kaizen. Possible Solutions: 5S, Visual Controls, Takt Time, Line Balancing, Single Piece Flow, Pull Systems, Layout Design, Quick Changeover, TPM, Poka Yoke, Standard Work	
			Inputs related to Outputs on IPO		Scatter Plots, Modeling, DOE	
	12	What is the list of improvements to be made? Are tests necessary? Is there a risk in implementing them?	Selected Solutions		Prioritization Matrix, Solution Grid, Customer Interview, DOE, Scatter Plots, Pugh Selection Matrix, **Bulleted List of Improvements**	
			Future State FMEA and VSMs		FMEA, VSM	
	13	What is the performance of the improved process? Did you meet your goal?	Implemented Solutions		5S, Visual Controls, Takt Time, Line Balancing, Single Piece Flow, Pull Systems, Layout Design, Quick Changeover, TPM, Poka Yoke, Standard Work, Process Changes	
			Re-assessment of Capability		Capability Study (Product Capability, Cpk Charts), **Hypothesis Testing**, Data Collection, Histogram, Control Charts, **Run Charts, Box Plot,** OEE	

Lean Six Sigma Project Mentoring Guide (continued)						
	Control:	**Questions:**	**Deliverables**	**Date Complete**	**Recommended Tools**	**Comments**
Control	**14**	How will you sustain the improvement?	Control Plan		Control Charts, **Control Plans,** Error proofing, **Accountability,** 5S audit	
	15	What is the benefit from the improved process? Is it documented?	Validated Financial Benefits		COPQ Tracking, **Financial Verification**	
			Documented Results		**Complete Project Presentation, Project Database**	
			Documented Scalable Projects		Communication Plan, Project Database, Complete Project Presentation	
	16	Has the team been rewarded?	Team Recognition		Reward and Recognition Policies	