Production improvement techniques in process industries for adoption in mining: A comparative study

Lanke Amol
Divison of Operation and Maintenance Engineering,
Luleå University of Technology
Luleå, Sweden.
email:Amol.Lanke@ltu.se

Amol Lanke is a PhD student at Luleå University of Technology. He has worked as a business excellence implementer for Nestle and as a Business excellence manager with Mahindra Industries. He has completed his bachelors in Mechanical engineering from Shivaji University, India and Master of Industrial Engineering from Texas A & M University, USA. He is currently working of adoption of production assurance program for Swedish mining sector.

* Corresponding author

Ghodrati Behzad
Divison of Operation and Maintenance Engineering,
Luleå University of Technology
Luleå, Sweden.
email:Behzad.Ghodrati@ltu.se

Behzad Ghodrati is Associate Professor of Maintenance and Reliability Engineering at Luleå University of Technology, Luleå, Sweden. His research area is Reliability Engineering and Product Support considering Machine Operating Environment. He has published more than 45 papers in international journals and conference proceedings and a book chapter. He was recently involved in four national and international industrial projects in mining and railways in Sweden.

Lundberg Jan
Divison of Operation and Maintenance Engineering,
Luleå University of Technology
Luleå, Sweden.
email:Jan.Lundberg@ltu.se

Jan Lundberg is Professor in both Machine elements and in Maintenance at division of operations and maintenance at Luleå University of Technology, Luleå, Sweden. His main research topics are maintenance optimization of stationary and mobile mining machinery and railway related research. He are also performing research in the field of innovations, creativity, decision support models as well as engineering design of machine components to maximize the reliability and to minimize the maintenance.
Production improvement techniques in process industries for adoption in mining: A comparative study

Abstract

High profitability and customer satisfaction are of supreme importance for any business. To achieve both objectives, an organisation must design a structured approach. To achieve profitability, organisations look to principles of lean manufacturing and techniques such as EFQM, business excellence. This paper reviews such methodologies across different industries, comparing techniques and elements. Its objective is to determine which methodologies are most applicable to the Swedish mining industry and propose a method to achieve lean mining. To this end, the paper looks at the methodologies of a food manufacturing industry, an automobile component manufacturing company, the manufacturing and service sector, and the oil and gas industry. It finds that the method used in the oil and gas industry is more relevant to mining, even though it has some flaws. Further research is needed to adapt this method to the mining industry.

List of Abbreviation used

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSC</td>
<td>Business Score Card</td>
</tr>
<tr>
<td>CBM</td>
<td>Condition Based Maintenance</td>
</tr>
<tr>
<td>DMAIC</td>
<td>Define, Measure, Analyze, Implement, Control</td>
</tr>
<tr>
<td>EFQM</td>
<td>European Foundation of Quality Management</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Mode and Effect Analysis</td>
</tr>
<tr>
<td>FNA</td>
<td>Flow Network Analysis</td>
</tr>
<tr>
<td>GOR</td>
<td>Gas Oil Ratio</td>
</tr>
<tr>
<td>HSE</td>
<td>Health Safety and Environment</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Process Indicators</td>
</tr>
</tbody>
</table>
1 Introduction

To deal with competition, organisations must have a well-planned and structured approach to customer satisfaction, as this is directly linked to profitability. Profitability depends on a number of different factors in an organisation according to Singh and Ahuja (2012). For example, operations must be reviewed and reconstructed to meet throughput times, minimise operating costs, and improve the quality of products and operations. Successful execution is complex and depends on such factors as organisation readiness, execution, human factors, and organisational hierarchy. Therefore, a structured methodology is required, one that encompasses the whole organisation to make the entire process effective, efficient and adaptable to changing business needs. As Lee and Chang (2010) pointed out, goal of many structured methods is to improve on variation, operational measures and achieve business objectives. Since the mining sector is affected by the same complexities and problems as other industries, the aim of this paper is to review a number of structured methodologies in terms of their objectives, elements, implementation procedures and success, and to determine which are more suitable for mining. Mining is a key factor in the economic growth of industrialised nations; it is widely assumed that a country with extensive mineral resources has great potential for wealth. Increased industrialisation globally has led to increased demand for minerals; the mining industry has responded by increasing its output. For example, the world iron production jumped 41% between 2000 and 2011 (Brown et al., 2013). To meet the challenge, the mining industry has turned to automation, mechanised many mining jobs, introduced computerised mining maintenance etc.

2 Scientific Approach

The thorough examination of each method is done by following guideline.
• The type of industry is similar to the mining industry in its classification based on type of manufacturing practice?

• The objectives of these methods align with objectives of mining industry for achieving higher demand and achieving profits by satisfying the increased demand?

• How the adoption of method for achieving the objective has been carried out?

Compatibility for adoption will require check on similarity of objectives and industry type. Implementation details will also be useful for knowing the tools and techniques used in these methods. Transforming goals into practice can be known by knowing implementation details.

In mining industry the lack of standard methods prompts a need for the structured method development. This study tried to compare methods in industries similar to mining. These methods have been established standards either by the specific industry or by international organisation. The study evaluates their implementation, structure and success. Comparison with objective in mining, methods and procedure requirements, this evaluation could be guidance for formation of method for mining industry.

In what follows, the various methods are discussed with respect to their objectives, implementation and success.

According to the American Production and Inventory Control Society (APICS) definition, mining is a process industry. The four methods reviewed in this paper are taken from industries which can also be categorised as process industries; therefore, their methodologies may be applicable to mining. The study’s goal is to propose a suitable methodology for adaption to mining industry, one that addresses the issue of achieving higher output for customer satisfaction and profitability. The first approach is used by a food industry; the second is from an industry that manufactures magnets; the third is applicable to the process industry and also to other types of industries and services; the fourth is used in an oil and gas industry in Norway. The companies using these methodologies are all achieving their business objectives. In what follows, the various methods are discussed with respect to their objectives, implementation and success. The description of the method used in the food industry and also in an automobile component manufacturing factory is found in field studies performed by the specific organisations. The discussion draws on the organisation’s manuals and experiences implementing the method. Next, the European Foundation for Quality Management (EFQM) and PAP are explained in detail. For EFQM, various research materials are available from EFQM (for example, see http://www.efqm.org/); we also draw on references from (Watson, 2002; Hides et al., 2004; Yang et al., 2001). For the Production Assurance Programme (PAP), we use a specific guideline, namely, ISO 20815. Finally, we compare the capacities of the methods (see Table 2). Once this has been established, we apply the methodologies to mining. The requirements of the mining industry have been explained in earlier research; these requirements are set against the objectives, tools and techniques and focus of the various methodologies. The fit of these requirements is illustrated in Table 3. The results shown in the table lead to our selection of the best methodology for mining. We conclude by noting the remaining gaps and suggesting further research.
3 Review of methodologies

In this section, we review various approaches used in process and manufacturing industries to achieve their business objectives. The first is an excellence programme used by a food manufacturing giant. This programme is used across its factories making food and allied items. For food manufacturing organisations, profitability is related to output quality versus cost, optimal supply chain management, avoiding downtime, reducing spill over, increased flexibility of manufacturing, employee education and training, and productivity and increasing capacity utilisation (Harris et al., 2002; Mason et al., 1994; Paul, 2003). The second method, Mahindra Quality Way (MQW), is used by Mahindra Mahindra, a prominent automobile and auto component manufacturer from India. As for other industries of these kinds, for MQW the factors leading to profitability include:

- Overall Equipment Effectiveness (OEE), which covers availability of equipment, quality of output and performance of the equipment (Jonsson and Lesshammar, 1999)
- Product innovation (Lager and Hörte, 2002)
- Reduction in process variability and quality costs

The third method, EFQM, is an assessment methodology which guides numerous organisations around the world in achieving and evaluating system reliability for increased performance. EFQM is not restricted to any one method or tool; rather, it analyses the structure of a methodology and assesses its practices. The fourth method is PAP, developed by the Norwegian oil and gas industry and converted into an ISO standard. PAP is designed in such a way that it can play a significant role in supporting the decision-making process for output capacity and customer satisfaction/loyalty challenges in the petroleum sector.

3.1 Method used in a food industry

Business objectives frequently focus on achieving profitability through customer service and efficiency. A prime example is the food manufacturing industry (Mason et al., 1994; Paul, 2003). The company we discuss here has adopted a programme for continuous excellence which uses tools and techniques adapted from Six Sigma and lean manufacturing. The objective of the continuous excellence programme is threefold:

- Improve customer satisfaction
- Compete globally by staying ahead of the competition
- Ensure regularity in operations and compliance with regulations and laws

To achieve these objectives, various decisions such as expansion of product range are formulated by the top level of management; these decisions, in turn, are communicated to the management of individual factories. As strategies channel efforts towards goals (Pedrinaci et al., 2009), implementing the continuous excellence programme at the organisational level starts with factory management formulating a strategy, including the projects to be carried out, collaborations needed within the factory and external agencies, and capital and operating expenditures. The strategy includes managerial decisions along
with the time-line for each decision. The industrial performance department assesses capacity through specially made software. Capacity and supply planning are simulated using current data from the production system and used to plan the following month. Once approved, these plans will be used by the Supply Chain Management (SCM) department for ordering. Each department head decides on a course of action to achieve the objectives outlined in the overall factory strategy. To determine the state of completion of the objectives, a number of Key Performance Indicators (KPIs) are measured (see Table 1).

Table 1: Key process indexes, their owners and objectives (Aramyan et al., 2007; Bigliardi and Bottani, 2010; Torkko et al., 2013)

<table>
<thead>
<tr>
<th>KPI</th>
<th>Owner</th>
<th>objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output per day over 3 shifts</td>
<td>Production</td>
<td>Achieve required output</td>
</tr>
<tr>
<td>Stoppage of each line</td>
<td>Production/Maintenance</td>
<td>Achieve target of minimum hour stoppage</td>
</tr>
<tr>
<td>Rejection by day</td>
<td>Production</td>
<td>Reduce Rejections</td>
</tr>
<tr>
<td>MTBF for major equipment</td>
<td>Maintenance</td>
<td>Increase MTBF</td>
</tr>
<tr>
<td>MTTR</td>
<td>Maintenance</td>
<td>Reduce MTTR to set standard.</td>
</tr>
<tr>
<td>Work order generated v/s work orders completed</td>
<td>Maintenance</td>
<td>Keep Machinery&amp;equipment available and reliable</td>
</tr>
<tr>
<td>Rejections versus Production</td>
<td>Quality</td>
<td>Achieve quality parameters</td>
</tr>
<tr>
<td>Non conformity reported versus their closure</td>
<td>Quality</td>
<td>Help Production and Maintenance department in knowing where is problem lies.</td>
</tr>
<tr>
<td>Customer complaint received versus customer complaints addressed</td>
<td>Quality</td>
<td>Customer satisfaction/Compliance</td>
</tr>
</tbody>
</table>

The production department, maintenance department and other allied departments work together to form the production plan. Optimisation at the micro level requires a close focus on daily operations. To this end, a daily review meeting is led by the production department and attended by representatives from the other departments. KPIs are discussed using graphs and charts. Any lag in any KPI is discussed and analysed for operating problems. Solutions are proposed and converted into short and long term actions. These actions are then formally written down, along with the date for performing the specific action, and followed.

In this industry, the quality of food products is key factor. Therefore, quality is checked at various points during the production process. As the initial quality of the raw material is checked upon receipt, since traceability is an important KPI in the quality department. In the production process, the quality is checked again, this time for ingredient levels, the Ph of the produced material etc. This is done by means of on-line sensors. After the production is completed, quality is checked by a test taste. Another way to check the product quality is to put the product on the shelf for various time limits to test
its time dependent characteristics. The quality check is done according to the Hazard Analysis and Critical Control Points (HACCP).

Depending on the problems already encountered in operations and maintenance, each department head will formulate Six Sigma projects to improve upon the existing system. Six Sigma is a set of techniques and tools for process improvement. Because of the continuous demand for cost savings through improved manufacturing efficiency and process optimisation, this system is used by many industries, including food manufacturing (Lewis, 1998). The maintenance department uses these tools for continuous monitoring of production lines and supportive machinery. They provide data which are later analysed along with data from work orders to achieve optimal efficiency. Condition monitoring is done using regular checks and audits such as energy audits. This methodology leads to improved KPIs.

By using continuous excellence as a core technique, one food manufacturing company achieved annual savings of 1.675 billion USD in 2012, along with capital efficiency improvement and organic growth.

### 3.2 MQW: Method used in an automobile component manufacturing industry

The Plan Do Check Act cycle developed by Walter Shewhart in 1930, and then improved upon by W.Edward Deming, forming the name of method as "Deming wheel" (Sun et al., 2007). Based on the PDCA, Mahindra Mahindra, one of the largest manufacturing groups in India, designed their own quality improvement model, the Mahindra Quality Way (MQW). The objective is an integrated approach to promote excellence in all processes and operations. The goal is to efficiently achieve the company’s business objectives and meet the needs of stakeholders (Mahindra and Mahindra., 2009). The features of the MQW programme are as follows:

- Systematically promote the use of comprehensive quality management
- Lay equal emphasis on process and results
- Provide framework for systematic planning of improvement
- Encourage self-examination as a primary means to strive for excellence
- Seek involvement and participation of all employees
- Annual review of progress

This program can be adopted in various business scenarios and for various products. Each factory/plant decides how to use the model. The current discussion is taken from a factory manufacturing magnets (Mahindra Hinoday industries Limited) for various applications in the automobile and electronics industries.

Each year, the organisation produces a PDCA cycle review and strategy. This document serves as pivotal point for maintenance department decisions on the optimal use of equipment. The PDCA cycle also dictates which actions should be taken for the next year to achieve the projected revenue. BSC is formed using the results obtained last year and comparing it with next year’s goals.

A business Score card framework combines financial, customer, internal process. This helps managers and companies in understand in interrelationships and causal effects.
Which leads to improved decision making and problem solving (Hashemkhani Zolfani and Safaei Ghadikolaei, 2012). BSC is thus useful for converting strategy into operational terms. Therefore, the BSC is the starting point of the MQW process. The objectives for each production process are then derived from the BSC objectives. The BSC goals are finalised using the PDCA document along with business results obtained from the finance and control department. The resulting BSC is used by each department head to create that department’s own BSC.

Each departmental BSC is then converted to a PDCA document, an action plan which considers the life of equipment, output required and results to be achieved. Each action listed in the PDCA document will have timelines for starting and finishing that action. A Standard Operating Procedure (SOP) is prepared and revised every three months with the help of the operators and the engineering supervisor. An SOP helps in operating and maintaining the equipment within the operators’ capability. Maintenance SOPs are also created; these specify how the machine or equipment should be maintained for a specific set of problems. Failure Mode and Effect Analysis (FMEA) uses input from the production, quality and maintenance departments. Here, FMEA is related to a specific product and, hence, is called Product Failure Mode and Effect Analysis (PFMEA).

The maintenance department uses Time Based Maintenance (TBM) and Condition Based Maintenance (CBM) for the equipment. The priority for TBM is decided according to the age of equipment and criticality of equipment for production process. Thermal imaging and vibration analysis are part of routine checks. Audits are performed by quality department for process and product SOP implementation. Operators and management staff are trained in various topics, such as ISO 16949 and MQW. Frequency of check differs at each level. Control chart are filled and used by operator on-line for checking deviation in the process. The types of defects generated during the operation and in line checking for other aspects is done by operator on the machine. The supervisor in charge checks for output and the parameters for the whole line. These are then reported to engineer at the end of three shifts. Engineer then analyse the 6 causes of deviation and applies corrective action. The reporting is carried out every day at departmental level.

The department heads keep track of their own BSC. Any deviation is discussed with engineers and analysed. The department heads take any required action; this usually consists of decisions about maintenance by an external agency or capital expenditures.

The deviations which cause the most problems in output and delivery are analysed every three months. The products and the top three defects are then analysed using a Pareto chart and affinity diagram. Quality Control stories (Kano, 2003) are used as a methodology to attack the causes of defects and eliminate them from the production line and process.

Every year the departmental BSC is checked against the PDCA plan; the aggregated results are compiled in a PDCA document and used to formulate the next year’s BSC.

Many organizations that are part of the Mahindra Mahindra Group have shown tremendous growth. For example, Mahindra Hinoday Industries went from negative to positive profit in 2011-2012. An internal company report attributes this partially to MQW.
3.3  EFQM: Method used in various types of process industries across Europe

Quality of management is crucially important for achieving success in market. With these principles, the president of one of Europe’s biggest businesses established the European Foundation for Quality Management (EFQM) in 1998. EFQM defines excellence as outstanding practices in managing organization and achieving results (Breja et al., 2010).

With EFQM, organisations can measure where they are on the path of excellence and understand the gaps. The EFQM excellence model seeks to achieve the following objectives:

- Assess performance to identify key strengths and improvement areas
- Integrate existing tools, procedures and processes to align them and remove duplicates
- Introduce a way of thinking that encourages reflection and stimulates continuous improvement
- Identify what actions are driving results, which areas need more attention, and which approaches should be made redundant

EFQM has the ability to encompass all operations in an organisation and all types of organisations. The value of the EFQM model depends on the ability of an organisation to assess nine criteria. These criteria are divided into two categories, enablers and results. Enablers or agents define what organisations must do to achieve excellence. These enablers are determined by a company’s directors, managers of human and material resources, and process managers (Calvo-Mora et al., 2006). They define how an organisation can achieve its targets, i.e. the best techniques to use. The criteria used by organisations adopting EFQM for optimisation and improvement are shown in Figure 1 and their relative importance is weighted in Figure 2.

![EFQM Criteria diagram](EFQM, Accessed 2013-02-13)

Implementing EFQM starts by questioning the performance of an organisation, using RADAR logic, which stands for results, approach, deployment, assessment and review. The first step of RADAR logic is that top management must be willing to use EFQM. The next stage starts with planning the results to be achieved. The results of an organisation may include financial results, operational results and/or the results required by
the stakeholders. The formation of the plan and the strategies required to achieve the desired results may include the creation of key process indicators. Depending upon the results required specified at each stage, the details of the plan may differ throughout the process.

EFQM does not have a prescribed methodology for execution, but the next step is creating a deployment schedule and process. The final stage includes self-assessment and review and is extremely important as this can be used to set benchmarks or plans of excellence. The methods of self-assessment include:

- **Workshops**: The workshop approach has five stages:
  - Training,
  - Data collection,
  - Scoring,
  - Prioritisation of improvement actions,
  - Review of progress

- **Pro forma approach**: Creating documentation of criteria, strengths, areas of improvement etc.

- **Questionnaires**: This approach is less labour intensive and thus preferred over other approaches. These may be simple yes or no type questions or more detailed questionnaires. The accuracy of the answers may depend on the quality of the questionnaire and the response rate.

- **Matrix charts**: The approach requires phrasing statements on what can or will be achieved. Then each statement for either the enabler or result criteria is assigned a rating on a scale of 0 to 10.

- **Award simulation**: Organisations using this approach prepare a document which lists the fulfilment of EFQM criteria. This document is then submitted to external or internal trained assessors who provide feedback.
Each of these approaches to self-assessment allows an organisation to review its results. It will know where it stands in terms of reaching excellence. The assessment also suggests directions for further improvement. EFQM does not prescribe any particular methodology, machinery, equipment, tools or techniques for improvement and optimisation. Rather, it evaluates the current methodology in an organisation, and tries to aggregate and formulate the best practices for that an organisation. The EFQM model has been tested and used effectively in various manufacturing industries/service sectors, including higher education, the IT industry etc. (Adebanjo, 2001).

In fact, its applicability ranges from manufacturing to service industries, as evident in the variety of success stories listed on EFQM website. Organisations using EFQM include Rank Xerox, ICL, Rover, BT, The Post Office (Royal Mail United Kingdom), TNT Express and Glaxo (Lascelles and Peacock, 1996; W ongrassamee et al., 2003).

3.4 PAP: Method for oil and gas industry

As in many other manufacturing industries, oil and gas industry profitability depends on such factors as Overall Equipment Efficiency (OEE), the availability and reliability of equipment and the throughput ratio. If we look at the consumption versus the production of oil over recent decades, we find that the consumption of world oil has been rising since 1965. Demand increased by about 13% between 2000 and 2011 (Dudley, 2012). At the same time, however, global oil production showed a growth rate of about 10.5% between 2000 and 2011 (Dudley, 2012).

With supply lagging behind demand, the oil and gas industry must optimise the available resources to achieve customer satisfaction and profitability. There has been research on reducing uncertainty in the system and achieving profitability. Each aspect of oil production has been studied and analysed by researchers looking for ways to improve operations (Heiberg et al., 1981; Engen and Rausand, 1982; Cron and Marsh, 1983; Venkatesh, 1986; Brown and Lea, 1985). For example, Production Availability Forecasts (PAF) were used to analyse reservoir performance as early as 1984 (O’Brien et al., 1984). The PAF technique was also used to analyse the Gas Oil Ratio (GOR) for optimum short-term reservoir management, a method applicable to accelerated oil production (Chang et al., 1986; Brouwer et al., 2004). In addition, research has considered how to distribute the economy of throughput across the operations involved in oil and gas productions to reduce the fixed costs associated with production and achieve maximum output. In 1988, Hokstad (1988) from Sintef proposed a model for calculating production regularity in subsea production systems. Such efforts were supported by the governments of a number of countries. In 1978, the USA formed a committee to study the productability of oil and gas; the committee’s purpose was to determine the constraints on and opportunities for increased domestic oil and gas production (Fisher, 1983). Reliability engineering was used in various other research efforts to determine probable management costs and, thus, optimise them (Bello and Avogadri, 1982).

The objective of earlier research was to ensure that the process of oil production was reliable and robust by reducing system uncertainty for a single system. The next step was to amalgamate the research on production ability, production regularity availability, and throughput to address the reliability and regularity of oil and gas production across
all operations. Aven (1987) combined these terms and proposed the use of availability analysis to ensure the reliability of production. A more holistic approach was introduced in the 1998 standard NORSOK Z016 created by the Norwegian oil and gas industry. This standard combined all aspects of oil and gas production operations and associated systems with evaluation and improvement using Reliability, Availability, Maintainability and Safety (RAMS) analysis. The objective of this standard included management of the facility for optimal economy without comprising on health, safety, quality and human factors, i.e. regularity of production. The term regularity of production was later replaced by production assurance when NORSOK Z016 was made part of ISO 20815: Petroleum, petrochemical and natural gas industries—Production assurance and reliability management. ISO20815 covers the following:

- Production-assurance management for optimum economy of a facility through all life-cycle phases, while also considering constraints arising from health, safety, environment, quality and human factors;
- Planning, execution and implementation of reliability technology
- Application of reliability and maintenance data
- Reliability-based design and operation improvement

While NORSOK Z016 gives little explanation of the processes involved in the creation of a production assurance program, ISO 20815 gives a clear idea of the activities required in each step. It gives guidelines for designing a Production Assurance Program (PAP) and specifies what activities should be carried out in each of the 12 processes involved.

The objectives of PAP are to:

1. Reduce system uncertainty in oil and gas industry operations and design, thus satisfying customer demand and achieving profitability.

2. Identify and execute opportunities for improvement in operations and maintenance of the system for better productivity, thus satisfying objective 1.

The core activities of processes required to create a production assurance program are the following

1. PAP starts by defining the boundaries of a project, i.e. clarifying exactly what is to be achieved. The input for this process includes project plans (asset development, field layouts, availability analysis etc.)

2. The next step is to formulate a plan for executing the project, i.e. defining the PAP. The PAP document generated during this step is used for completion of achievements stated during the first step.

3. In the third step, existing systems and operations are designed and/or modified to meet the production assurance objectives formulated in steps 1 and 2. The tools used in this process are performance data, reliability analysis and availability analysis and their results, and risk identification. The objective is to improve upon the existing system.

4. The fourth step involves implementation production assurance whereby activities are reported on and execution is checked.
5. The fifth step, reliability and risk analysis, ensures that the technical safety and reliability of equipment is being considered in the early phases of the process. It supports the asset development plan. This phase is purely technical and is associated with oil and gas operations specifically.

6. The objective of the sixth step, verification and validation, is to ensure that the new production assurance program can achieve its goal. In addition, all Health, Safety and Environment (HSE) regulations must be satisfied and incorporated.

7. Finally, performance data tracking and analysis assist in the validation and verification process; an organisation can determine the exact status of the system and define areas requiring improvement. Thus the results of seventh step can be used in step 3, as this is an ongoing process.

4 Results and Discussion

4.1 Comparison of methods

It can be seen from the each method study that,

- The food industry mentioned here uses six sigma with lean principles in a number of processes, from forming a strategy at the factory level to implementing the strategy.

- MQW uses a PDCA approach in its implementation. This approach is modified and adapted to meet the needs of specific factory and industry operations to reduce system waste.

- EFQM provides a framework for an organisation to achieve its business objectives.
- PAP implementation resembles classic PDCA methodology: processes 1 to 3 of the core activities are “plan”, processes 4 and 5 represent “do”, process 6 is “check” and process 7 along with process 3 indicate “act”.

The main difference between PAP and other methods is that the focus of PAP is on reducing system uncertainty by increasing equipment reliability and availability. The techniques of reliability and availability analysis comprise a core part of the PAP process.

The various methodologies discussed above can be briefly summed up as follows (see Table 2)

<table>
<thead>
<tr>
<th>similarities and disparities</th>
<th>Method in food industry</th>
<th>MQW</th>
<th>EFQM</th>
<th>PAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives/principle of the program</td>
<td>Satisfy customer demand.&amp; Strongly face competition. Compliance with regulation and frameworks.</td>
<td>To improve upon the process and satisfy customer demand to achieve business goals (Profitability)</td>
<td>Adding Value for Customers Sustaining Outstanding Results (EFQM)</td>
<td>To reduce uncertainty and achieve profitability while satisfying customer demand</td>
</tr>
<tr>
<td>Methodology for achieving objectives</td>
<td>Structured methodology DMAIC adopted from Six Sigma and lean mfg. principles</td>
<td>Structured methodology which follows PDCA cycle. Lean mfg. principles.</td>
<td>Constructs and assess structured methodology</td>
<td>Structured methodology with 7 core processes involved</td>
</tr>
<tr>
<td>Tools and techniques</td>
<td>BSC, Six Sigma &amp; lean manufacturing tools, TBM, Performance monitoring and analysis.</td>
<td>PDCA reviews, BSC, FMEA, TBM, Performance monitoring, QC story</td>
<td>Radar logic enabler and results criterion, standardized examination &amp; risk analysis.</td>
<td>reliability analysis, performance and availability analysis, FMEA, FNA</td>
</tr>
<tr>
<td>Application</td>
<td>Food and allied products manufacturing.</td>
<td>manufacturing industry, Automobile mfg. Service sector, IT.</td>
<td>Various industries including process and service industry</td>
<td>Oil and gas industry</td>
</tr>
<tr>
<td>Similarity with lean manufacturing</td>
<td>Reduction of waste and improve performance using Kaizens</td>
<td>Reduction of waste and improve performance.</td>
<td>Reduction of waste. improvement in all aspects</td>
<td></td>
</tr>
</tbody>
</table>

It is seen from the table that, MQW and method from food industry has a specific objective of profitability, whereas for EFQM and PAP, the objective is focused on demand satisfaction and results achievement. In this regard it can be said that irrespective of the method used objectives are focused for industry it is used in. Although each method uses different tools and techniques, structural construction of these tools and techniques is necessary. This will help logical flow while a method being implemented. This is evident from the implementation of MQW and food industry method. The structural flow also helps while detailing the task for performing under the method. Example of structural flow can be explained with example of MQW method. During the MQW method control charts are used for close monitoring of the process, this close monitoring thus demands
operator involvement. The analysis of data performed in MQW requires engineering skills; hence this task is assigned to engineer rather than operator.

The tools are techniques explained for each method are different. BSC is used in both MQW and food industry method as a document with overview of actions to be performed across organization. Performance monitoring through the control charts, online monitoring are the tools at the shop floor level. In EFQM the questionnaire prepared acts as direction for guidance. It may contain direction for overall improvement across organization or a specific improvement to be performed at a shop floor level. PAP standard does not prescribe such overall guidance or document preparation. It does however mention reporting of the actions and logging of improvement in the handbook.

In case of MQW, the selection of tool, techniques and structure of methodology has made it widely adoptable across the various types of organization under the Mahindra group. Similarly the adoption of food industry method has made the food industry conglomerate achieve higher results specifically in terms of profitability as mentioned earlier. EFQM being produced specifically for the automobile industry has been adopted in other industriues including service, discreet manufacturing etc. PAP was made specifically for oil and gas industry and thus has been converted into standard for same industry.

This comparison shows that although the methods are different, adopted and used in different types of industry, their use and adaptability for success of an organization is possible. It seems that these method thus could be good candidate for the adoption in mining industry.

4.2 Requirements in mining industry.

There is an increased global demand for minerals, and the mining sector is seeking to meet that demand (Brown et al., 2013). At the same time, however, a mining company must consider the costs involved. There are two main costs in the mining sector: operating and maintenance costs. In surface mining, for example, some estimate the cost of maintenance as 30 to 50% of the total operating cost (Topal and Ramazan, 2010). Others say this cost can range from 20 to 35% of the total operation cost (Dhillon.B.S., 2008). The accidents and fatality rates are higher than average industry rates (Dhillon.B.S., 2008). Although the number of severe accidents has been reduced, the number of non-severe accidents has increased in Swedish mining companies since 2011 (Föreningen för gruvor, 2013). Thus, safety continues to be a key concern.

The mining industry is heavily dependent on equipment for its output. Thus, equipment availability and reliability are extremely important (Dhillon.B.S., 2008). Researchers suggest that reliability and availability analyses are required during the design phase of the equipment itself (Dandotiya, 2012; Kumar et al., 1989; Wijaya et al., 2012).

To summarise the requirement of mining industry can be enumerated as follows.

- Satisfy the increase in demand,
- Consider cost of maintenance and operation,
- Consider reliability and availability of equipment i.e. maintenance intensive methods;
• Consider safety in the workplace,
• Consider reliability and availability during equipment design.

The general operation sequence in mining is as follows

Exploration → Planning → Extraction → transport → Processing → distribution.

Oil and gas industry operations is divided into Upstream and downstream operations. The operations involved in upstream process are explore, develop, produce, gather, treat/process, and transport oil and gas to market (i.e., to refineries, petrochemical plants, distribution system, and consumers) (Verma et al., 2000). Similarly in the industries studied product is developed, processed and then distributed. There is operations similarity between studied industries. However due to nature of product, operations detailing and equipment differ significantly.

Table 3: Production assurance primary requirements in mining and its fulfilment by methods

<table>
<thead>
<tr>
<th>Requirement in mining</th>
<th>Food industry Method</th>
<th>MQW</th>
<th>EFQM</th>
<th>PAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting tight schedule and achieve demands</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Improvement in operations</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Reduction in accidents</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>✓</td>
</tr>
<tr>
<td>Reduction in operation cost</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>✓</td>
</tr>
<tr>
<td>Reduction in maintenance cost</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>✓</td>
</tr>
<tr>
<td>Reliability of Equipment</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>✓</td>
</tr>
<tr>
<td>Availability analysis</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>✓</td>
</tr>
<tr>
<td>Focus on maintenance</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>✓</td>
</tr>
<tr>
<td>Design of Equipment focus</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>✓</td>
</tr>
<tr>
<td>Operation similarity with Mining</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>partially satisfies</td>
</tr>
</tbody>
</table>

● = does not satisfy the criteria, ✓ = satisfies the criteria

Table 3 shows how the methods studied here fulfill the mining industry requirements. When compared with mining requirement following points are observed.

1. The objective of achieve high profitability by improvement in operations is a common between four method studied. Making them viable for adoption in mining from the objective perspective.

2. Accident avoidance is major criteria for mining industry. To address this issue PAP has mention of procedure to be followed. Reduction in staoppgaes due to accidents is not part of improvement program in other 3 methods. In MQW and food industry method focus is given on prevention of accidents. Improvements are performed for prevention, these improvements are later converted to method for avoidance. As a holistic method, handling of accidents is not addressed in discussed methods above. EFQM safety assessment requires development of the safety questionnaire related the particular organization (Chinda, 2012). This limits
the EFQM assessment for safety in various organization. In mining the safety criteria is dependent upon manufacturers. Achieving mining safety though assessment will require further research. This limits use of EFQM for accident handling in mining.

3. Maintenance and design of equipment for maintenance avoidance is not evident in 3 methods studied. PAP address this issue with design and manufacturing step of the method specifically.

4. Reliability analysis is another strong point of PAP method, which is essential for the mining industry. Mining operations are continuous as similar to the oil and gas industry. Any laps in reliability of equipment and operation can lead to the loss of production on large scale. PAP was developed through expansion of the reliability analysis program for oil and gas industry. PAP thus mentions type of reliability analysis to be performed along with mention of tools of reliability analysis. Requirement of reliability thus make PAP a strong contender for adoption in mining industry.

5. The three other methods tend to be more simplistic than PAP in their implementation, giving clear-cut instructions, such as what specific action must be taken by the person on the shop floor or by the production manager and where this action takes place. Such instructions do not consider the optimal use of resources across the whole organization, rather look at each factory and each machine separately. EFQM is non-prescriptive; its assessment tools allow a company to form a framework depending upon organisational practices. The PDCA and Six Sigma approach can be applied to various types of industries and is widely used (Breyfogle III, 2003; Salah et al., 2010). In contrast, PAP does not give a method or technique for singling a problem out and applying a specific method to remove or reduce this anomaly.

Considering the operational similarity studied methods could be used for adoption in mining industry. Comparison via Table 3 shows that out of 10 requirements for mining production assurance PAP satisfies nine.

5 Conclusion

To address the complexities in achieving higher production a structured methodology is lacking in mining industry. Various factor required for achieving production assurance, are studied through 4 methods from process industry in this study. These methods are useful in making process effective and efficient. MQW and six sigma used in food industry has shown direct correlation with profitability and structured methodology. Wide use of EFQM in various businesses and formation of ISO standard for entire industry accentuates success for EFQM and PAP. To address the lack of structured method in mining, adoptability of studied methods was checked. The adoptability was addressed through comparison of managerial /operational requirement in mining. The comparison showed that out of 4 studied methods, each methods satisfies the some requirement in mining. Although it seems that no method is directly applicable for mining.

Success of method used in food industry, MQW,EFQM are discussed. However the adoption of these methods for mining industry has limitations. The limitation stems due to
• Lack of addressing the accident as part of holistic method.
• Lack of maintenance supportive methodology.
• Lack of equipment design and equipment reliability study as part of method.

As Table 3 shows, PAP is better suited for adaptation and use in the mining industry than any other methodologies studied. Interestingly, the two largest Swedish mining companies use a type of improvement methodology which resembles PAP.

Although PAP is based on lean principles, however, it lacks certain features to contribute to the objective of lean mining and has the following shortcomings:

1. PAP considers operations optimisation and managerial aspects of the business such as system design and equipment reliability using reliability and maintainability as main performance indicators. But these need to be detailed and standardised.

2. PAP does not provide detailed steps for implementation. This is necessary, as reliability and availability analysis and performance tracking for mining will require different sets of key performance indicators, given the specificity of the machinery and operations.

PAP effectively address the operational optimization and managerial aspects such as system design and equipment reliability using reliability and maintainability as main performance indicators. The limitation for PAP adoption in mining is due to lack of detailing of the reliability and maintainability procedure. A standardization of reliability and maintainability procedures for various equipment used in mining is essential. A method with which the maintenance is carried out to assure the reliability of equipment requires detailing, such detailing is not documented in PAP.

PAP is designed for oil and gas industry. Adoption for mining industry will require detailing of implementation. In its current format PAP lack such detailing. This is important for mining industry since reliability and availability analysis along with performance tracking of mining equipment will require different set of key performance indicators. In such case with lack of detailing, repetition of KPIs for all equipment and operations is possibility. Decision making from management based on these KPIs will result in errors, leading to loss in production and profitability.

5.1 Limitations of the research and future research directions.

Although PAP could be used by the mining industry to promote lean mining, more research is needed to examine existing methods in mining so that PAP can be implemented, with suitable modifications. The study shows that over all adoption of PAP could be useful. To form a cogent mining production assurance program, however detailed study of PAP and mining industry operations is required.

It was also seen that PAP has limitation in terms of detailing of implementation and method to follow. In future research direction it should be taken into consideration. Mining operation, variable affecting production and their relationship with each other must be studied for proposing production assurance program for mining in future.

More research is needed to examine existing methods in mining so that with suitable modifications PAP could be used to form lean mining method.


Dhillon, B. S. (2008), *Mining equipment reliability, maintainability, and safety*, Springer.


Föreningen för gruvor, m.-o. m. i. S. (2013), Occupational injuries and sick leave in the swedish mining and mineral industry 2012, Technical report, SveMin, Stockholm.


Venkatesh, E. (1986), Erosion damage in oil and gas wells, in ‘SPE rocky mountain regional meeting’.


