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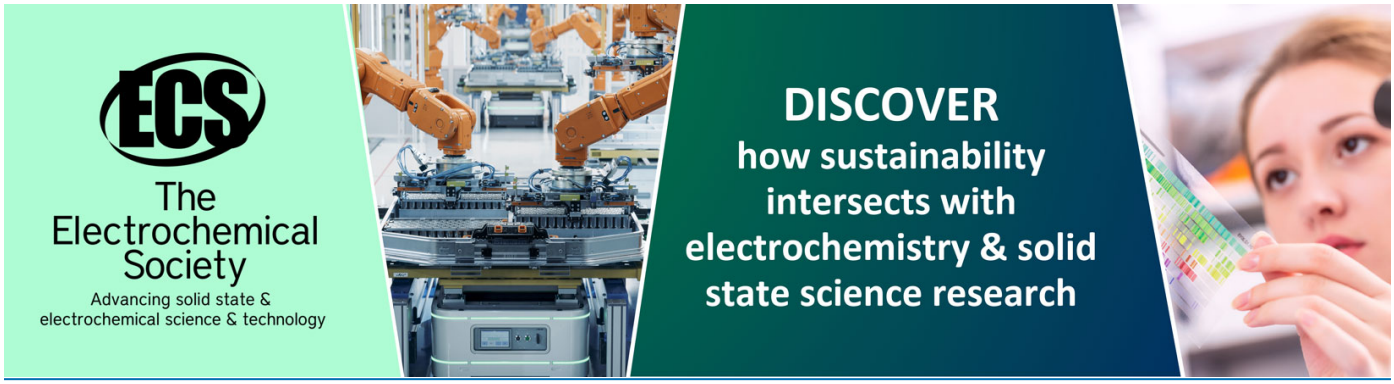

The application of Lean Management and Six Sigma tools in global mining enterprises

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Abstract. The article aims to present the currently most important two methods for production process streamlining, namely Lean Management and Six Sigma, and Lean Six Sigma, which combines the benefits of the preceding two. Lean, which originated in the Japanese automotive industry, is at present the most well-known and widely applied concept for the business cost reduction. It is also known as Lean Manufacturing or Lean Production. The system's main objective is to focus on cost-cutting in operations which did not add value for the customer. Six Sigma method seeks to ensure quality, or minimize variability, in processes so as to eliminate errors even before they appear. Six Sigma applies process execution methods that exclude the possibility of defects. A combination of these two methods provides a complete set of tools to improve the speed and efficiency of each process. The paper outlines cases of implementation of these methods in the world's mining industry and its financial effects. The synergy produced through a combination of Lean Management and Six Sigma is extremely powerful in this sector.

1. Introduction

The global mining industry, particularly its coal sector, has been experiencing a difficult period recently. Businesses have been grappling with low prices on the global market which tend to drop below mining costs. The world's mining industry is now increasingly on the look-out for organizational solutions to allow cost reductions in the mining and processing of fossil fuels. Such solutions are frequently imported from other sectors of industry. The on-going reorganization and restructuring of the Polish mining sector must aim for reduced mining costs and greater flexibility as their strategic goals. This will be impossible, however, without an overhaul of the approach to the management of mining enterprises. The article aims to present the currently most important two methods for production process streamlining, namely Lean Management and Six Sigma, and Lean Six Sigma, which combines the benefits of the preceding two. The article will also present examples of Lean Six Sigma implementation in mining companies around the world.

2. Lean Management Method

Lean Management is, at present, among the most well-known and widely applied concepts for the management of a manufacturing business. It is also known as Lean Manufacturing or Lean Production, shortened to Lean [1]. "Lean Management" is the most widespread term, especially following numerous cases of successful implementation in the service sector [2].

Lean originated in the automotive industry. Starting in the 1950s, Toyota undertook to create, implement and systematise tools, whose combination formed the Toyota Production System (TPS). The system's main objective was to shift the focus from mass production to cost-cutting where costs did not add value for the customer. In 1988, the system was named Lean by John Krafcik- one of the researchers involved in the International Motor Vehicle Program. The notion of Lean Manufacturing was made popular by James. P. Womack, Daniel T. Jones and Daniel Roos. In 1991, they co-authored the bestselling "The Machine That Changed the World," which pointed to Toyota Production System as the first lean production process [3, 4].

The application of Lean Management should result in a situation, where all the right items are in the right place at the right time. Particular efforts should be made to reduce the three main types of waste:

- Muda - production scrap, downtime, needless motion and waste of time, resources and other activities which do not contribute any value for the customer.
- Muri - overburdened employees, machines or processes, resulting in tiredness, repeated machinery failures, increased downtime, etc.
- Mura - unevenness and inconsistency of operations - management of the flow of resources in such a way as to ensure consistency, steady flow of work and operational smoothness [3].

There are five fundamental Lean principles which may be applied to an enterprise as a whole, individual processes or the actions of a specific employee:

- define which actions add value for the customer,
- identify all the actions necessary to create a product along the entire value chain to tease out those steps which represent waste,
- create a new, waste-free value chain with no downtime, disruptions or backflow, etc.
- do what the customer requires,
- aim for perfection by eliminating the instances of waste which you have identified [5, 6].

Lean creates a work culture in the organization which motivates all its members to steadily reduce costs, improve quality and shorten lead times. All this has the aim of providing maximum satisfaction for the customer and flexibly aligning oneself to the surroundings. The idea seeks especially to eliminate all waste, or non-value-adding activities. Lean Management may be seen as a new enterprise management philosophy, a new organization of enterprise or as a system of concepts and management methods [7]. The most important tools include: PDCA, Jidoka, Just in Time, TPM - Total Productive Maintenace, Visual Management, 5S, Kaizen, Standarization, SMED, Kanban and Heijunka.

Following benefits of Lean implementation are the most commonly mentioned [8]:

- reduced costs,
- reduced lead times,
- waste reduction,
- improved productivity,
- reduced work in progress (WIP) inventory,
- reduced defects/improved quality.

Like most management systems, Lean does not come without its own set of disadvantages [9]:

- supply chain tension problems,
- high costs of implementation,
- lack of acceptance by employees,
- customer dissatisfaction problems.

There are a few other Lean Management disadvantages, like [10]:

- lack of strategic focus,
- lack of proper IT systems,
- lean takes time and can be very disruptive.

3. Six Sigma Method

In the late 1970s, cheap Japanese goods were becoming increasingly competitive on the global markets, forcing American companies to seek ways to improve their product quality while, at the same

time, keeping the costs low. In a joint effort, General Motors, Ford and Chrysler made large-scale use of SPC - Statistical Process Control, which enabled them to steadily track the manufacturing process at critical points of quality and costs. Similarly, Motorola, which was being driven out of the market by cheaper and superior Japanese products, gathered a group of distinguished experts in mathematical statistics, design and quality assurance, who worked together to develop a consistent system for constant improvement of quality, known as "Six Sigma Initiative." The system also allowed progressive reductions in prime costs through COPQ - Cost of Poor Quality. This enabled Motorola to reduce poor quality costs over just a few years from 40% to around 1% of the value sold [11].
Rather than focus on the product, the Six Sigma method seeks to ensure quality, or minimize fluctuations, in processes so as to eliminate errors even before they appear. Six Sigma gives processes precedence over products, applying process execution methods excluding the possibility of defects [12].

Harry and Schroeder point out that Six Sigma is an economic process allowing enterprises to improve their financial health through planning and controlling the workflow in such a way as to minimize the consumption of raw materials and the production of waste, while at the same time providing more satisfaction for the customer [13].

It is difficult to give a clear-cut, complete and universal definition of Six Sigma, for it interacts very strongly with the company's culture and takes on a different individual form everywhere. In fact, it is advisable, as a recipe for success, to create one's own "6 Sigma path." This is because the projects, training and available infrastructure should, in each case, be adjusted to the needs and capabilities of the specific organization [14]. Six Sigma's strong point is a clear division of responsibility and duties between employees, precisely defined requirements for applicants seeking a position in the company as well as an extensive system of training [15].
The most important tool which drives Six Sigma is the DMAIC excellence algorithm [13]:
- Define,
- Measure,
- Analyse,
- Improve,
- Control.

Six Sigma has become a key method in many large corporations thanks to its impact on the management culture. This innovative method is increasingly gaining ground in more and more organizations, which is why it is being applied in a growing number of industrial sectors [16].

The main benefit of Six Sigma is its positive financial impact due to cost saving, risk reduction in process variation, a common tool set, problem-solving approach, and project linked with business objectives [17].

Six Sigma is criticised as offering nothing new than traditional quality management practices. It is argued, that the large returns from this methodology at some companies were due to the initial quality level of these companies being so low that anything would have drastically improved their quality [18]. Because Six Sigma is applied to all the aspects of the production and planning process, it may create rigidity and bureaucracy that can stifle creativity and flexibility. Additionally, its customer focus may be taken to extremes, where internal quality-control measures that make sense for a company are not taken because of the overlying goal of achieving the Six Sigma-stipulated level of consumer satisfaction [19].

4. Lean Six Sigma Method

Lean and Six Sigma are separate systems for process improvements, as far from each other as Japan and the USA. Companies which have adopted Lean base their activities on Kaizen, i.e. constant improvement, day after day, step by step. To better organize their work, they use methods learned from Toyota's experience, such as: 5S, visual management, Andon, Heijunka, TPM, SMED and PDCA. Six Sigma was named after standard deviation sigma, a parameter used in statistics. The use of the Six Sigma methodology helps to improve productivity and reduce business costs. The overarching

aim is to provide customers with a product suitable to their expectations by eliminating process fluctuations [20]. Benefits in Six Sigma come from the elimination of poor quality costs. Use is made mainly of hard analytical and statistical tools such as SPC, MSA and DOE. Improvement in 6 Sigma is DMAIC-based, progresses in leaps, looks more spectacular and, for that reason, feels more "American".

Lean and Six Sigma can complement each other despite their differences [20]. The two methods are similar in their action algorithms. DMAIC is used to streamline the existing processes. This algorithm builds and elaborates on Deming's PDCA (Plan, Do, Check, Act) circle used in Lean Management [21]. The similarity of algorithms is presented in figure 1.

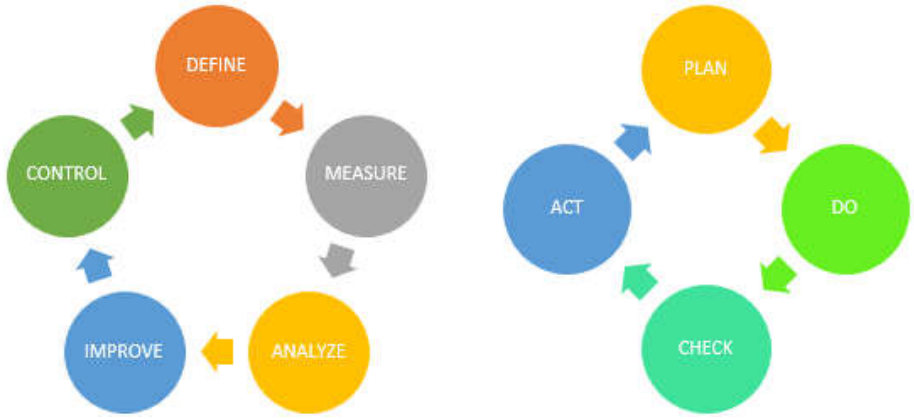

Figure 1. DMAIC algorithm and PDCA circle.

Lean Six Sigma is a two-step business approach to steady improvement with a focus on eliminating waste and reducing fluctuations in manufacturing and service processes. Lean aims for maximising added value for the customer while, at the same time, keeping waste to a minimum and making economies in resource consumption. Six Sigma is a lasting effort to steadily reduce fluctuations through a defined approach to processes. Taken together, these two approaches make for constant improvement, serving as a philosophy underlying effective system management in any organization wishing to develop intensively [22].

Lean and Six Sigma are mutually complementary. Lean drives 6 Sigma to produce better results than those achieved by Lean and Six Sigma separately. A combination of these methods provides a streamlining team with a complete set of tools to improve the speed and efficiency of each processes within the organization for more profit, better cost reductions and closer cooperation [23].

5. The application of Lean Six Sigma in the mining industry

Lean and Six Sigma together offer a set of tools which may be used in mining to improve efficiency. More importantly, however, the methods may be applied to transform the business by fostering a culture of excellence in the senior management who has a good understanding of what good value is and how to estimate it. Lean is a way of thinking, a philosophy with a focus on the human being, aiming mainly to improve people who will in turn do a fantastic job of improving the processes. Six Sigma delivers scientific methods of management and stabilizes processes. At this point, it is worth mentioning that focusing too much on only one of these methods quickly leads to failure. The goal is not the method itself, but the results we are trying to achieve. More importantly, an effective implementation of these excellence methods depends, to a large extent, on qualified mediators who know the mining industry and can adjust quickly to this rough business. Nothing can replace experienced specialists who understand the importance of constant business improvement and

employee training. These are necessary to get a bird's-eye view of the system and make proper use of data for decision-making [24].

German mining enterprise RAG AG is a good example of Lean thinking implementation. Activities aimed at eliminating losses and creating standardized processes started there in 2000 under the slogan "Zero Accidents and 100 Percent Value Added".Lean processing guidelines for this programs are[25]:
- Creating values from customers view point,
- Look at the whole value stream,
- Pull principle for processes,
- Synchronised flow,
- Search for perfection.

RAG transferred many existing tools to the mining context and invented special tools for mining processes. Two examples for this transfer are the tools SMED and the PDCA/DMAIC cycle. RAG calls it Boxenstopp and APUC cycle, which stands for analyze, planning, implementation, controlling (Analyse, Planung, Umsetzung, Controlling)[25]. Rag's version of PDCA/DMAIC algorithm is presented in figure 2.

Figure 2. APUC cycle - RAG's version of PDCA/DMAIC [25].

In 2000 the RAG started with the implementation of Lean as a pilot in the business processes of one mine. Therefore the necessary tools (5S, Visual Management, teamwork, elimination of waste, Pull system, Boxenstopp, organization analysis) were introduced to the workers in sequence. After the first successful steps, the launch of Lean and its tools went on in the production of the other mines. Afterwards the RAG included the supporting processes like the development, the machine maintenance and the logistic as well as the management and administration processes[26].

RAG uses the 5S, elimination of waste, teamwork and the organizational analysis for the production as well as for the administration. Whereas Pull System, Boxenstopp and Visual Management are mostly used in the production. Especially the optimization of the interactions between all these divisions was an important aspect for creating processes without any wastes. Therefore RAG transferred the seven wastes into the mining context.In many meetings, working groups and qualification trainings, seven wastes idea was presented and discussed with the miners and the management. With this background they were able to identify wastes in their processes, develop measures and eliminate the problems. Searching for overproduction, waiting times, unnecessary transportation, movements or inventory and defects or corrections become part of the daily work and improvement routine[26].

There are five Lean-principles RAG's employees and management have to keep in mind when they work on their processes[26]:
- create values for the customers, that means stable and effective processes without waste,
- look at the whole value stream, not only at elements thereof,

- organize activities in a synchronized flow without interruption, backflows, detours and waiting,
- pull principle - customer or the following process step initiates the working process,
- establish a continuous improvement process.

For the development of Management Systems, there are six success factors from RAG´s experience [25]:
- Establishing organisation,
- Systematic approach,
- Measuring the results,
- Participation of employees,
- Management acting like coaches,
- Talking and informing each other.

Other good example of Lean in mining industry is KGHM Polska Miedź – one of the largest producers of cooper and silver in the world.Lean Management way of KGHM started in 2011 with the program "Adaptation and implementation of Lean methodology in copper mines", which has 5 areas [27]:
- Lean Mining,
- Kaizen -employee ideas,
- Total Productive Maintenance,
- process approach,
- modelling and simulations.

Examples of implemented Lean tools in underground cooper mine department, in Heavy Machines Chamber are [28]:
- new maintenance KPI's: MTTF, MTTR and MTBF,
- standardization of repair procedures
- checklists for repair processes,
- demanded spare parts catalogues.
- new labelling guidelines for Heavy Machines Chamber.

After implementation of TPM tools in ore processing department, company highly improved their processes. In Figure 3, there is an example of reducing failure rates of 4 filter presses in ore processing department.

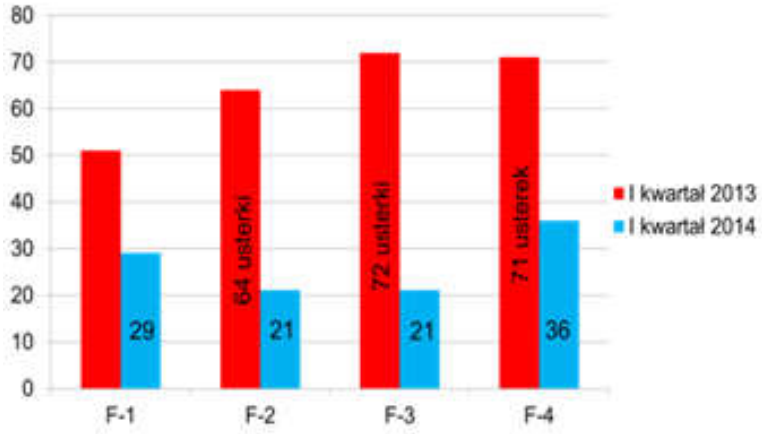

Figure 3. Reducing failure rates of 4 filter presses (comparison of 1Q 2013 and 1Q 2014)[29].

Other examples of profits of Lean implementation in KGHM processing ore department [29]:
- elimination of the chain conveyor of the crusher dedusting system, thus achieving a zero fault level,
- reduction of total stop times by 11%, including those planned by 8%, unplanned by 45%,
- improvements in suction pipelines - threefold extension of trouble-free operation.

Many other mining companies have tried to implement Lean and Six Sigma.

Alcoa was one of the first raw materials company to implement Toyota Production system and develop an off-shoot of its own, known as Alcoa Business System (ABS) [30].

According to IQPC (International Quality and Productivity Centre), ever since the combined strategies for business excellence, Lean and Six Sigma, made their way into the Australian mining sector, there has been strong evidence that the efforts have produced overall process improvements, leading to higher returns on investment [24].

In 2008, Klippel, Petter and Antunes reported two cases of Lean-based mining process mapping. Value stream mapping was used to classify activities as value-adding and non-value adding (necessary and unnecessary). Specific action was taken to eliminate non-value-adding activities and minimise waste, resulting in material benefits such as increased productivity, cost reduction and improved safety in the workplace [24, 31].

Rio Tinto Group began implementing Lean in aluminum ore mining in 2004, supplementary to the Six Sigma improvement programme. Next, the project was extended to include copper, coal and iron ore mining sectors, mainly in Australia. Dunstan, Lavin and Sanford, in line with their definition of Lean as understood by Rio Tinto ("constant elimination of waste"), have proposed that, in practice, Lean means [32]:

- activating cell leaders,
- requesting employees to comply with the agreed-upon terms of employment,
- allowing employees to draw up and improve their own standards,
- presenting visually the key data related to manufacturing efficiency (visual management),
- enabling lowest-tier employees to make data-based operational decisions,
- organizing operational and maintenance employees into manufacturing teams,
- applying a packet of tools to streamline operations.

Rio Tinto Group named its Lean Six Sigma program "IPT" (Improving Performance Together) and uses it now in all its business units [33].Rio Tinto Alcan uses Six Sigma and Lean Manufacturing tools to streamline processes and improve efficiency. Only in 2008, the savings generated for Rio Tinto Alcan by Lean Management and Six Sigma amounted to USD 28,000,000 [34].

BHP Billiton has a similar programme called Business Excellence. A number of plants of this group, with their operations on oil-bearing sands in Canada, have implemented the rules and methods of Six Sigma to lessen defects and waste in the manufacturing operations related to the production of bituminous materials [24].

Quandra FNX Mining (now KGHM International) had its own program known as "Raising the Bar." The programme was based on the proper application of Lean Six Sigma tools, starting from value stream mapping for the entire process, to lay down a reference point for efficiency, using standard definitions and indicators (KPI - Key Performance Indicators). This intense group activity served to gather staff from various departments, allowing them to communicate about creating value and identifying waste and non-value-adding activities. The first contact with VSM is definitely an eye-opener for most participants. In some cases, this is their first chance to see the process as a whole and understand their role within it. They begin to understand value as being customer-defined and ask questions not only limited to the day-to-day running of the company [24].

The Diavik diamond mine also channelled its resources into the Lean 6 Sigma operational excellence programme. The method used by Diavik aimed to make operations more efficient by eliminating reduplicating or unnecessary activities and automatizing processes as much as possible. The focus was on a thorough re-thinking of processes and defining what can be done better, more quickly and cheaply [35]. All of Diavik's departments were obliged to find ways to cut costs. All savings must be safe so that a safe balance is not disturbed. Underground process automation and Lean 6 Sigma initiative are examples of sustainable activity. The success was that the cost-reducing ideas came from employees and subcontracts at all levels of the organization. The total amount of savings in the first half of 2013 was USD 6,000,000. The forecast for the second half of 2013 envisioned

additional savings to the amount of USD 4,000,000 generated by 28 lean 6 Sigma projects in progress [35].

6. Conclusions

Numerous differences exist between the automotive industry, where Lean was born, and the mining sector. This is why implementations need an individual approach in each case. The examples of successful implementations of Lean in mining have shown it to be the correct path of development [36]. Lean focuses on small, day-to-day adjustments, while Six Sigma pays more attention to large optimization projects spanning many months to provide a rapid surge in efficiency, quality and cost savings. Despite its primary focus on hard statistical and analytics tools, Six Sigma has frequently drawn on Lean Management tools. Lean itself is slightly worse at handling highly automatized processes and organizations where prime costs are the highest. Synergy is created by combining these two approaches.

The synergy effect may be particularly powerful in the mining industry. There, we see a manufacturing model in constant transformation, a frequent reduplication of functions and processes, a traditional work culture where employees are not meant to improve the organization. This makes it a fertile ground for Lean Management. On the other hand, the industry features highly automatized processes and high fixed costs, making it suitable for Six Sigma.

Mining companies are adjusting Lean Six Sigma to their needs by using a programme under their own individual name. The examples of RAG AG, KHGM, Rio Tinto and others presented here prove that the implementation of this method is possible and may bring large, measurable benefits.

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