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Manufacturing Continuous Improvement Using Lean Six Sigma: An Iron Ores Industry Case Application

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Abstract

In Iron Ores Industry, manufacturing process capability is an important factor for business continuity. There are some problems faced in manufacturing process that caused inability to fulfill the manufacturing quantity target. In order to improve the manufacturing process capability, this research is conducted using lean six sigma method. The first part is focused on waste analysis using process activity mapping. Then manufacturing process capability is evaluated. Further, failure mode and effect analysis is used as a basic consideration in developing the continuous improvement program. The research shows that the quality performance is in the level of 2,97 sigma. There are 33,67 % non value added activity and 14,2% non necessary non value added activity that occurs during the manufacturing process. Based on the analysis, product defects, inappropriate processing and waiting are type of manufacturing waste that frequently occurs. A continuous improvement program is develop to overcome that problem. The program consist of redesigning chute dust collector, weighing standard operation procedures, BC 05 erection, vibro meter installation and nitrogen plant installation.

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Keywords: *Lean six Sigma; Manufacturing Process Improvement; Mining Industry*

1. Introduction

The process of making iron ore is known as sintering, a series of iron ore formation process before entering into smeltering process. The output smeltering process is smelting process of metal before it's being used in casting

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process for a wide range of products. PT. S is a company that produce iron ores as shown in Fig. 1. This product can be categorize as semi finished products that ready to be processed further in the milling process.

Fig. 1. Sample of Product PT S

In a mining industry, the production capacity is important for company's sustainability. With new commissioning, PT. S only capable to produce 12% of production target. The risk of losses incurred by the company during the past two months are Rp. 588..801.463, -. This condition occur due to several production waste.

Waste is any non value added activity during production process. Production wastes are categorized into two types, namely type 1 is waste that does not provide added value along the production flow but this activity can not be avoided for various reasons [1]. And type 2 is a waste that do not add value and should be immediately reduced.

There are several method to minimize the production waste. Lean six sigma method has been broadly accepted by the manufacturing industries to improve its production performance. The function of this method are to identify and minimize waste or non-value added activities through continuous improvement [2]. Implementation of lean six sigma in a cable manufacturing company have been done [3]. The research purpose is improving product quality through data collection of product defect, data analysis using failure mode and effect analysis (FMEA) and give some corrective action to reduce the level of product defect. Beside that, research of lean six sigma effect to the company have been done [4]. Based on this research, lean six sigma have a positive impact on quality improvement, financial advantages, benefits for the customers as well as employees.

Therefore, a production improvement strategies using lean six sigma is needed to improve production performance of PT S and minimize production waste. DMAI cycle (define, measure, analyze, improve) is used as the basis for research. The output of this research is company's performance improvement.

2. Basic Theory

2.1. Lean manufacturing

Lean Manufacturing is a systematic approach to eliminate waste and change processes. This is done by identifying and reducing waste with continuous improvement [5]. Lean Manufacturing seeks to create a production flow throughout the value stream by eliminating all forms of waste and improve value-added products to customers [6]. There are seven waste by Shigeo Shingo, namely: overproduction, defect, unnecessary inventory, inappropriate processing, excessive transportation, waiting /idle and unnecessary motion [7].

2.2. Six Sigma

Six Sigma is a process gives more value to customers and stakeholders with focused on improving product quality and company productivity [1]. There are five stages called DMAIC method (define, measure, analyze, improve, control).

2.3. Process Activity Mapping (PAM)

Process activity mapping can be used as a tool to determine the proportion of detailed activity, which are grouped into value added (VA), necessary non value added (NVA) and non-value added (NVA). Process activity mapping is used to identify the waste or non-value added activity that occurs on each production process.

2.4. 2.4. Failure Mode and Effect Analysis (FMEA)

Failure mode and effects analysis is a methodology designed to identify potential failure modes of a product or production process, considering the risks based on failure modes, and to identify and implement corrective actions [8]. Risk priority number (RPN) is a critical indicator to determine the appropriate corrective actions related to failure mode. RPN is used in the FMEA procedure for estimating the risk using three criteria, namely: severity, occurrence and detection [1]. Priority number RPN is the product rating severity, occurrence, and detection that shows the ranking of corrective action needs.

3. Research Methodology

Data processing is done by six sigma DMAI cycle, so systematically the integration of lean manufacturing and six sigma as being expected. The first stage is identification of production waste during drying iron ore process in PT. S. Measurement of waste carried out by qualitative assessment. In the Measure phase, pareto diagram is used to determine the critical waste and defect per million opportunity is used to measure product defect. Then root cause analysis is done to evaluate several factors causing waste. Critical waste selection carried out using FMEA method. In the improve phase, alternative solution are given to reduce production waste and improve production performance.

4. Result and Discussion

4.1. Define

The main process of an iron ores are smoothing, storage, processing of iron ore, fuel transfer, fuel injection process, positioning on the drop point, quality control, and shipment. Based on process activity mapping, operational activity consist of 4,3%, transport activity consist of 28,91%, inspection activity consist of 6,68%, storage activity consist of 6,79% and delay activity consist of 10, 31%. From that production activity, the value added activity (VA) consist of 52.13%, non value added activity (NVA) consist of 33.67% and non necessary non valuea added activity (NNVA) consist of 14.20%. The production of drying iron ore is not optimal due to production efficiency only at the level of 52%.

Based on that condition, the company should make a new innovation to minimize non-value added activity in production. Type of waste identification during production process are shown in Table 1.

Table 1. Categorization of Waste

Type of *Waste*	Description
Defects	Fe content less than 51%
Inappropriate Processing	The process of heating up takes too long
	Fuel use too much
	Coal use too much
	Nitrogen use too much

Type of *Waste*	Description
Idle / waiting	Engine repair process (shutdown) take too long
	Engine shutdown schedule is not standardized
Unecessary Motions	Lack of hand pallet available for transporting material
	Bending and coupling when performing welding work
	Employees do not comply with the work schedule
Excessive Transportation	Repositioning material located in stockpile
	SE department position far lead to the need for access to a lathe using a vehicle
	Unavailability lift transport
Human Talent	Unskilled Labor
	Shift schedule does not run effectively

4.2. Measure

Waste Measurement

Based on the observations, several type of waste that have been identified are inappropriate processing, waiting/idle, excessive transportation, defects, unnecessary motions, and human talent. Then a qualitative assessment of waste occurrence is done. The most common and influential waste are as shown in Table 2. Type of production waste of drying iron ore that will be analyzed further are inappropriate processing and defects.

Table 2. Summary of Waste Measurement

No	Type of Waste	Frequency (%)
1	*Inappropriate Processing*	18,18
2	*Unnecessary Motions*	7,95
3	*Idle/ waiting*	32,95
4	*Excessive Transportation*	1,14
5	*Defects*	30,68
6	*Human Talent*	9,09

Process capability and Defects Per Million Opportunities (DPMO)

The standard level of hematite (Fe) are more than 51%. So, the product that contain below 51% of hematite (Fe) will be categorized as product defect. Therefore, some criteria that included in the critical to quality (CTQ) are:

a. Fe content of at least 51%, if below from that percentage, then the product is declared defective and should being rework.
b. The quality of iron ore is considered very good if moisture to a minimum.
c. The quality of iron ore is considered very good when loss on ignition (LOI) close to 0%. LOI itself is water that is crystallized in a mixture of iron ore raw material. Where in heating process, this LOI will be lost and lead to product mass is reduced due to evaporation.

Based on calculations, DPMO is at the level of 28.750. It means that from one million opportunities there will be 28.750 possibility that the production process will produced defects iron ore. The process capability is at the level of 2,96 sigma. It means that PT S are not capable to produce iron ores based on quality standard.

4.3. Analyze

Failure Modes and Effects Analysis

To determine the potential errors, failure modes and effects analysis is done by focusing on waste type inappropriate processing and defect. Some points that potentially lead to waste type in appropriate processing are six process, namely: when transferring the material on the apron feeder, movement of material from the chute dust collector to final disposal, the process of material weighing, material transfer from the rotary cooler end (chute system), N2 gas supply and coal grinding process on the coal mill as shown in Table 3. The potential failure of waste type defects is in the rotary kiln drying process error as shown in Table 4.

Table 3. Results FMEA Inappropriate processing

Process Function	Potential Failure	Potential Effects of Failure	Sev	Potential Causes/ Mechanism of Failure	Occur	Current Process Control	Det	RPN
Apron feeder material transfer	Material settle below the apron	Apron feeder upraised from its holder lead to broken rotary motor trip	8	Wet material	3	Visual	5	120
				Rotational speed of apron is too slow	9	Rotary Dynamo	6	432
				No hole below apron feeder	9	Visual	5	360
Material movement from chute dust collector	Wasted material and mixed with sand	Income loss	8	Chute dust collector design	8	Rotary airlock	9	**586**
				Material handling design	8	Visual	7	448
Material weighing	Error Calibration	Different result from two device	9	Device is not calibrate well	9	Counter Weight	5	405
				No standard for material loss	9	Administrative	10	**810**
Rotary cooler end material transfer	Error material transfer	Material wasted in rotary cooler end	9	Design of chute system is not optimal	7	Standard chute outlet	3	189
		Material mixed with fabrication waste and sand	4	No drop out pool material in chute system	8	Excavator	5	160
		Material settled below BC 05 device	9	Height of BC05 close to sand	7	Measurement device	10	**630**
N_2 gas system supply	Broken safety mechanism	Gas N_2 release caused waste	7	Safety valve system	10	Pressure meter gauge	2	140
				Supplier fault	10	Weighing device	9	**630**
				Supply chain mechanism	9	Axapta ERP System	3	189
		Gas cylinder PGS explodes	10	Unsafety material handling	1	Loader	10	100
Coal Milling	Vibration in milling process	Broken milling table	8	Operator fault	7	-	10	**560**
		Unsmooth coal	5			-	3	105

Based on FMEA (*failure mode and effect analysis*), its known that the value of RPN for standard material loss has a value of 810, dust collector chute design is not appropriate has a value of 586, BC 05 height too low from the ground level has a value of 630 and the broken milling table due to operator error with a value of 560.

Table 4. Result of FMEA Defect

Process Function	Potential Failure	Potential Effects of Failure	Sev	Potential Causes)/ Mechanism of Failure	Occur	Current Process Control	Det	RPN
Rotary Kiln Drying error	Un optimum drying process	Low Fe	7	Kiln rotational speed and drying temperature setting	8	CCR	5	280
		High LOI	8				6	384
		High moisture	8				5	320
	Bear fire bricks are broken	Deformation of rotary Kiln	10	Temperature increase	4	Visual	10	400
	Broken lifter and UNP	Materials are not pushed into rotary cooler	9	Material size are big	7	Visual	8	504

4.4. Improve

Furthermore, a proposed improvement program is develop to overcome the problems that lead to waste inappropriate processing and defect. The proposed improvements program consist of:

a. Chute design dust collector
   To reduce wasted material, it is necessary to redesign chute dust collector in the form of a rotary airlock. Lock turnover continuously with a fabric tip can be modified to reduce the potential wasted material.
b. Standard operational procedure of weighing
   The development of standard operational procedure can be done by conducting operator training. The weighing process needs to be standardized, especially calibration precision scales recorded by belt conveyor to the weighing device before docking is done.
c. Erection of BC-05
   Erection of BC-05 is intended to avoid material that hampered in the bottom of conveyor. So in rainy weather, the material such as iron ore does not settle to the bottom of the conveyor.
d. Installation of vibrometer
   Vibrometer needs to be installed in outer surface coal grinder. Vibrometer installation is expected to anticipate an abnormal conditions.
e. Installation nitrogen plant
   With the installation of a nitrogen plant, the company is able to supply nitrogen which serves as an inert gas.

5. Conclusion

Based on the research, it can be summarized as follows:

a. From the production activity, non value added activity (NVA) consist of 33.67% and non necessary non value added activity (NNVA) consist of 14.20%. The production of drying iron ore is not optimal due to production efficiency only at the level of 52%.
b. The most common and influential waste are inappropriate processing and defect. the process capability is at the level of 2,96 sigma.

c. The proposed improvement program is develop to overcome the problems that consist of redesigning chute dust collector, weighing standard operation procedures, BC 05 erection, vibrometer installation and nitrogen plant installation.

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