Quality Control of Hot-Rolled Coil Production Process with Six Sigma Method in Hot Strip Mill Division of Steel Company

Arinda Soraya Putri, Husen Riza
Industrial Engineering Department, Faculty of Engineering, Universitas Muhammadiyah Surakarta, Jl. Ahmad Yani Tromol Pos 1, Surakarta, Indonesia
asp835@ums.ac.id, d600160068@student.ums.ac.id

Agung Pamungkas
Master of Industrial Engineering Program, Faculty of Engineering
Universitas Sebelas Maret, Surakarta, Jl. Ir. Sutami, 36 A, Surakarta, Indonesia
pamungkas@ft.uns.ac.id

Abstract

A largest steel manufacturing company in Indonesia and it places a premium on quality to ensure customer satisfaction. This research intends to identify the elements that contribute to the occurrence of defective products in order to develop a plan for reducing defective products in production outcomes. To quantify the degree of product defects in this study, the Six Sigma approach was utilized, which consists of Define, Measure, Analyze, Improve, and Control (DMAIC). The study focuses on common flaws seen in Hot Rolled Coil (HRC) products. According to the calculations, the three most common fault types are telescope, wavy, and chamber. The idea is presented as an attempt to improve in order to reduce the number of defective items. The findings of this research can be utilized to assess defective items and make modifications that the corporation can implement.

Keywords
Defect, Six Sigma, Hot Rolled Coil, Steel Company, Quality Control

1. Introduction
In modern times, such as now, the need for steel in Indonesia is extremely strong, as steel is one of the most commonly utilized elements in daily life (Aritonang 2019). Steel is used in a variety of applications nowadays, including building construction, automobile bodywork, culinary utensils, and much more (Savitri 2019). Many businesses compete with one another to provide high-quality, cost-effective goods.

The advancement and development of time has altered the consumer's perspective in selecting a desired product, one of which can be seen in how well the company has addressed three aspects of its manufacturing process zero defects (no defects), zero breakdowns (no failed processes), and zero accidents (no accident) (Corder 1973). These three qualities, however, are extremely difficult to achieve if the production process is not adequately controlled (Bakti, C. S., & Kartika 2020). Because it is directly tied to consumers and a reflection of the quality of the company's products, quality control to eliminate defects is critical (Safrizal 2016).

Companies must use quality control procedures in order to reduce defects or even achieve the goal of a defect-free product (Hani 2017). An successful product quality control program can lead to improved market penetration, as well as increased productivity and decreased production costs (Montgomery 1996). However, if a product's standards do not match and the product reaches the hands of consumers, the corporation will suffer losses (Nugroho and Kusumah 2021). Losses might range from the replacement of incurred production costs to the loss of consumer confidence in the company (Soemohadiwidjojo 2017). A method or notion of continuous product quality control is required to solve quality problems that develop (Andiwibowo et al. 2018). Total Quality Management (TQM), Statistical Process Control (SPC), and Six Sigma are all examples of industrial quality control methods (Montgomery 1996). The tools used in SPC will help in achieving process stability (Wulansari, R. E., Khasanah, A. F., & Djunaidi 2020).

Hot Rolled Coil (HRC) is a product of an Indonesia's largest steel company. HRC is manufactured by one of the company's plants, the Hot Strip Mill (HSM) (Fachrur and Karningsih 2017). According to the steel company, the HSM Plant produced 87.366 HRC units with 2.940 faults from January to December 2018. Even if the manufacturing process still results in flaws, the steel company always maintains a high level of product quality (Agung 2016).

Not all causes of product faults can be eliminated at the same time as a solution to the problem. Companies must be able to identify the issues that must be addressed initially (Sav 2018). As a result, study on quality control at the steel company utilizing the Six Sigma method is required (Purnama et al. 2016). Six sigma is a strategy for analysing the level of quality or the level of product damage till it approaches zero defects (Zasadzien 2017). The Six Sigma method is a set of concepts and procedures aimed at reducing variance and failure (Gaspersz 2005). The Six Sigma method, according to Regan (2012), can save money on warranty faults and the rework process. The company is projected to be able to prevent the occurrence of defective items through quality control, resulting in an increase in the company's perceived quality in the eyes of consumers (Nakhai et al 2009). As a result, the subject of this article is quality control in the production process utilizing the Six Sigma approach at the steel company's HSMPT division. The goal of this research is to examine defective products in order to generate research recommendations for improving the quality of the manufacturing process. Although there is substantial study on quality control using the Six Sigma method in the literature, there is less research on data analysis using SPC.

2. Methods

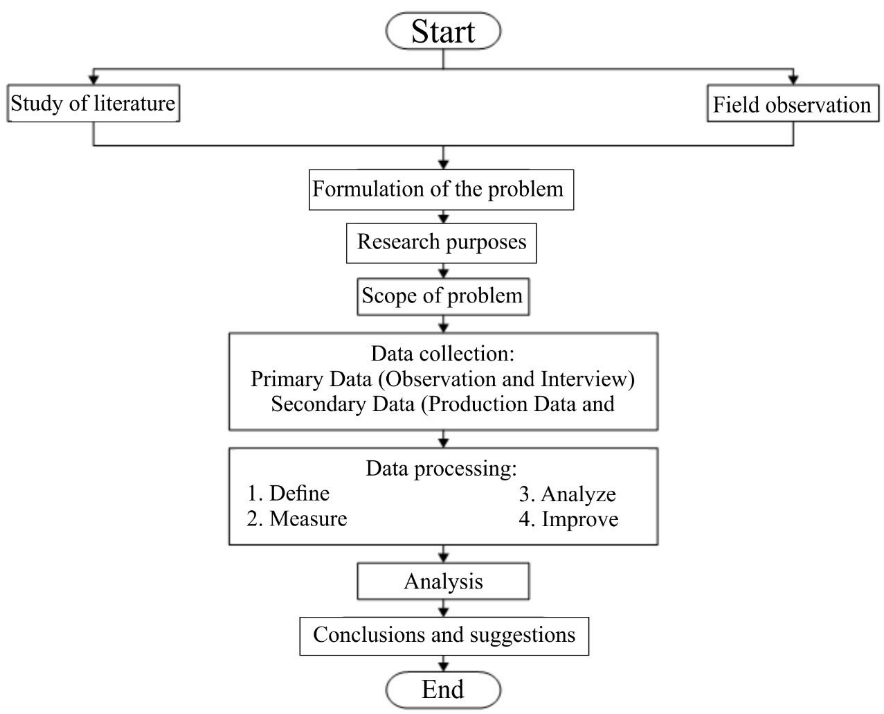

Figure 1. Research Method Flow Chart

A flow chart based on the study to be undertaken is shown in Figure 1. A flowchart is a visual representation of information that explains the research phase in the form of data flow. The flow chart in Figure 1 is explained in the following manner:

1. Start

The first step in problem-solving research is to get started.

2. Review of the Literature

A literature review is used to locate or prepare data and sources of information for use as a reference and for quality control purposes, as well as to locate primary and secondary data. The definition of quality, quality control, Six Sigma, the DMAIC cycle (Define, Measure, Analyze, Improve, Control), and Statistical Process Control were all investigated in this study (SPC).

3. Observation in the Field

Field observations are utilized to assess the company's true state. Direct observation of the manufacturing process can give the author with an overview of the company's challenges. In order to strengthen the writer's understanding, interviews were conducted.

4. Formulation of the Problem

An issue formulation was created in the company to be studied after performing a literature review and field observations. The goal of this research was to determine how the CTQ on the product, the DPMO value, the sigma level, the variables that cause product defects, and the efforts that the steel company must do to address these issues.

5. Goals of the Study

It is at this step that the research objectives are determined, as well as the solution to the problem formulation, which will be described in the conclusion. The goal of this research is to figure out what kind of flaws exist in HRC goods and which ones are the most common. To understand the DPMO and Sigma values of HRC goods, as well as the circumstances that cause defective products to occur, in order to improve the steel company's production quality.

6. Limitation of the Issue

The problem's restriction is that it is increased to the point where the research discussion does not grow and report writing becomes more focused.

7. Data Gathering

The author's data is a mix of primary and secondary sources.

  a. Primary information
    1) Direct observation, which is data collection based on direct observation of the object under investigation.
    2) An interview is a form of data collection in which the operator or person in charge of the manufacturing process is asked questions and given replies orally.
  b. Secondary Information
    Secondary data is gathered through monthly production processes or business reports, such as the following:
    1) Total production of an Indonesia's largest steel company during the 2018 period.
    2) Number of defective items produced by the steel company during the 2018 fiscal year.

8. Information processing

The next stage is to process the data obtained from the data gathering, which is done using the DMAIC method (Ganguly 2012). Make a project charter and figure out what is critical to quality (CTQ) (Define). The Pareto diagram describes the most common defects, calculates the DPMO value and Sigma level to determine the size of the failure in terms of the number of defects produced, and creates a control chart (Measure), cause-and-effect diagram to determine the problem that becomes the main priority, and then looks for the root cause (Analyze), and finally a proposed improvement that the steel company can implement (improve).

9. Examine

The purpose of the analysis is to convert data into information so that the data's features can be understood and used to existing problems.

10. Conclusion and recommendations

The research's conclusions and recommendations are presented in the final part. Conclusions are drawn from the conversation that has taken place and is in line with the research objectives. We also made suggestions that could be valuable to the steel company or the author.

11. Finished

This study will be finished once the final results are collected.

3. Results and Discussion

Six Sigma is an alternative to traditional quality control concepts, with the six sigma process allowing businesses to achieve amazing results through true breakthroughs. The use of quality measurement utilizing the Six Sigma approach at an Indonesia's largest steel company has several stages of analysis in this study, including define, measure, analyze, improve, and control, as follows:

3.1. Define

In the HSM division, define is the stage of defining quality problems for HRC goods. There are three categories of highest faults that may be described based on the results of observations and accessible data 313 telescope, 311 wavy, and 289 chamber. The defect data is shown in Table 1.

Table 1. The Steel Company's Monthly Product Defect Data

No	Defect Code	Description	Total	No	Defect Code	Description	Total
1	Tl	Telescope	313	20	Pt	Protruding	50
2	Wv	Wavy	311	21	Th	Out Thickness	44
3	Ca	Chamber	289	22	Rs	Roll In Scale	43
4	Wd	Width Out	227	23	Mw	Middle Wavy	36
5	Ov	Oval	192	24	Pr	Pinch Roll	36
6	Tc	Thickness Change	142	25	Ed	Defect Handling Php	23
7	Ed	Edge Defect	116	26	Sb	Torn	23
8	Ws	Water Descaler	110	27	Cm	Charter Mark	22
9	Cf	Couble Finishing	107	28	Bm	Black Mark	21
10	Lo	Loose	95	29	Rg	Out Roughness	18
11	Mn	Narrowing	94	30	Rm	Roll Mark	11
12	Ec	Edge Crack	92	31	Wo	Width Osilasi	8
13	Ct	Ct Out	86	32	Ws	Wavy Separating Disc	8
14	Dh	Defect Handling	80	33	Fo	Folding	7
15	Id	Identification	80	34	Wk	Wavy Curly	7
16	Ml	Widen	74	35	Mr	Mripk	5
17	Ef	Edge Fold	63	36	Tk	Less Flower Height	1
18	Ss	Scarfing Shell	55	37	Wf	Width Change	0
19	Rd	Red Scale	51	**Total Defect**			**2940**

The following is an explanation of the product's prevalent CTQ type:
1) *Telescope*: A telescope is a faulty kind of coil that occurs when a steel sheet is rolled unevenly and neatly. An example of a telescope flaw is shown below.
2) *Wavy*: The steel sheet is corrugated and unequal, resulting in a wavy flaw in the coil. The wavy' s shape can be observed in the image below.
3) *Chamber*: A chamber is a flaw in which the coil is curled in the shape of a banana or is not entirely straight. The chamber's form may be seen below.

3.2. Measure
The Measure is the measurement stage, which is split into two parts:

1) Examine the control diagram (P Chart)

HRC product data was acquired from the steel company's Hot Strip Mill division. From January to December 2018, measurements were taken on the product utilizing a Statistical Quality Control Type P – chart. The final product's mean (CL) or average is calculated using this information, namely:

$$\mathrm{CL} = \overline{\mathrm{P}} = \frac{\sum \mathrm{np}}{\sum \mathrm{n}}$$

$\sum np$ = Total number of damaged
$\sum n$ = Total number checked

CL calculation is as follows:

$$\mathrm{CL} = \bar{P} = \frac{\sum np}{\sum n} = 0{,}0157$$

Then determine the upper control limit (UCL) and lower control limit (LCL) as follows:

$$LCL = \bar{P} - 2\left(\sqrt{\frac{\bar{P}(1-\bar{P})}{n}}\right)$$

$$UCL = \bar{P} + 2\left(\sqrt{\frac{\bar{P}(1-\bar{P})}{n}}\right)$$

$\bar{P}$ = Average product damage
n = Total group/sample

The following is a table 2 of the results of the calculation of CL, UCL, LCL values:

Table 2. Value Calculation Results CL UCL LCL

Month	Defect /Month (Unit)	Total Production (Unit)	P	CL	UCL	LCL
Jan	108	6891	0.015	0.033	0.038	0.029
Feb	69	8006	0.008	0.033	0.037	0.029
Mar	107	8807	0.012	0.033	0.037	0.029
Apr	89	7880	0.011	0.033	0.037	0.029
May	122	7345	0.016	0.033	0.037	0.029
Jun	147	8055	0.018	0.033	0.037	0.029
Jul	313	6911	0.045	0.033	0.038	0.029
Aug	564	5282	0.106	0.033	0.038	0.028
Sep	335	5444	0.061	0.033	0.038	0.028
Oct	492	8003	0.061	0.033	0.037	0.029
Nov	364	8791	0.041	0.033	0.037	0.029
Dec	230	5951	0.038	0.033	0.038	0.029

The following criteria are used as a rule of thumb (Prawirosentono 2002):

a) If P<LCL, it means that the sample jumps down outside the receiving area, then check the cause.
b) If LCL<P>UCL, it means that all samples are in the receive region, which is called a sample with normal behaviour.
c) If P>UCL, it means that the sample jumps up outside the receiving area. It can be said that the process capability is low. It is necessary to check the cause.
d)

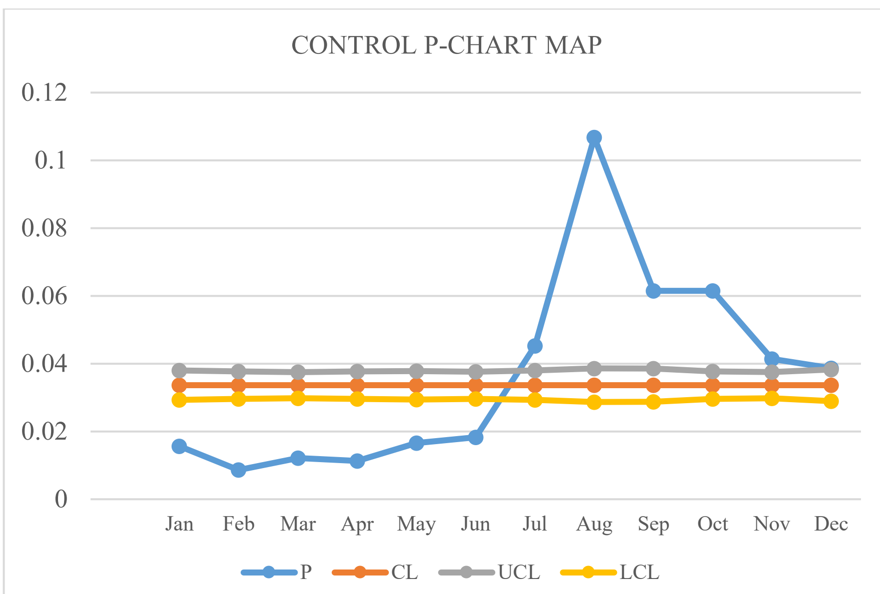

Figure 2. Control P-Chart

According to the P-Chart diagram above, multiple period points are placed above UCL, indicating that they are out of control, notably July to December, with each proportion 0.045, 0.106, 0.061, 0.61, 0.041, 0.038. August is the most populous month (Shown in Figure 2).

2) Values of DPMO and Six Sigma

The next stage is to perform a qualitative analysis of the data to determine the state of HRC product quality in the company. The sigma value is then calculated to identify the direction and improvement targets. The value of DPMO and Six Sigma is measured in the table below.

Table 3. Shows How to Calculate DPMO and Six Sigma Numbers

Month	Defect	Total Production (Units)	Defect Rate	DPMO	Six Sigma
Jan	108	6891	0.015	15672.616	3.652
Feb	69	8006	0.008	8618.536	3.881
Mar	107	8807	0.012	12149.427	3.752
Apr	89	7880	0.011	11294.416	3.780
May	122	7345	0.016	16609.939	3.629
Jun	147	8055	0.018	18249.534	3.591
Jul	313	6911	0.045	45290.117	3.192
Aug	564	5282	0.106	106777.74	2.743
Sep	335	5444	0.061	61535.636	3.042
Oct	492	8003	0.061	61476.946	3.042
Nov	364	8791	0.041	41405.983	3.234
Dec	230	5951	0.038	38648.967	3.266
		Mean		36477.488	3.400

The monthly product defect statistics for the steel company is shown in Table 3. In January, here's an example of how to calculate the DPMO and Sigma values.

a) Defect Rate / DPU

Defect per Unit is a structural condition that allows for the possibility of failing to fulfil client requirements.

DPU $= \frac{number\ of\ defects}{number\ of\ production} = \frac{108}{6891} = 0.015$

b) DPMO Value

DPMO s a process performance metric that calculates the number of failures per million opportunities.

DPMO $= \frac{number\ of\ defects}{number\ of\ production}$ x 1.000.000 = 0.015 x 1.000.000 = 15672.62

c) Value of sigma

The sigma value of HRC products computed using Microsoft Excel Software.

Sigma = NORMSINV(1- $\frac{DPMO}{1.000.000}$) + 1,5 = 3.653

According to the data above, the steel company's output in 2018 has a sigma value of 3.4, indicating that it is in a 3 sigma situation with a potential damage of 36.477 units per million productions. If the production process is not improved to limit the amount of damage that happens, the company will undoubtedly suffer a loss.

3.3. Analyze

The next stage is to analyze, analyze, and determine the error problem. This stage is used to determine the factors that produce errors in HRC products. At this point, a Pareto diagram is used to identify the three most prominent CTQs, and a fishbone diagram is used to determine the reason of any CTQs that have happened thus far, so that the problem can be effectively addressed. The following is a CTQ estimate for HRC products produced by the steel company in 2018 (Shown in Table 4).

Table 4. HRC Product CTQ Calculation

No	Defect	Description	Total	%
1	Tl	Telescope	313	10.6%
2	Wv	Wavy	311	10.6%
3	Ca	Chamber	289	9.8%
4	Wd	Width Out	227	7.7%
5	Ov	Oval	192	6.5%

No	Defect	Description	Total	%
6	Tc	Thickness Change	142	4.8%
7	Ed	Edge Defect	116	3.9%
8	Ws	Water Descaler	110	3.7%
9	Cf	Couble Finishing	107	3.6%
10	Lo	Loose	95	3.2%
11		Etc	1038	35.3%
	Total		2940	1

Based on the table above, the Pareto diagram is shown in Figure 3 obtained as follows:

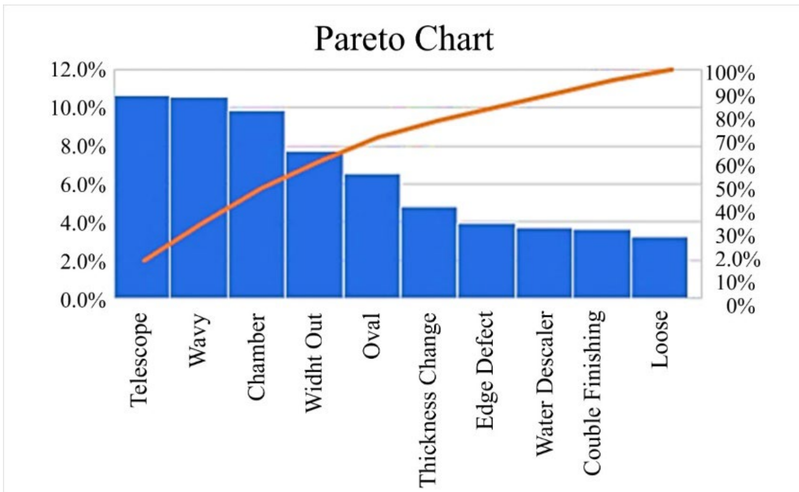

Figure 3. Pareto Chart of Defects

The most common faults are telescope defects (10.6%), wavy defects (10.58%), and chambers (9.8%) as shown in the Pareto diagram above. The most common defect is then repaired first in this investigation. The three types of defects, in addition to accounting for the majority of defects, necessitate rework, which incurs additional expenditures. The following is a causal diagram of the HRC products' telescope, wavy, and chamber defects:

1) *Bonefish Illustration of telescope flaws*

In the production of the HSM steel company division, the following is a cause diagram of a telescope flaw, which is a defect in the coil where the steel coil is uneven and neat (Shown in Figure 4).

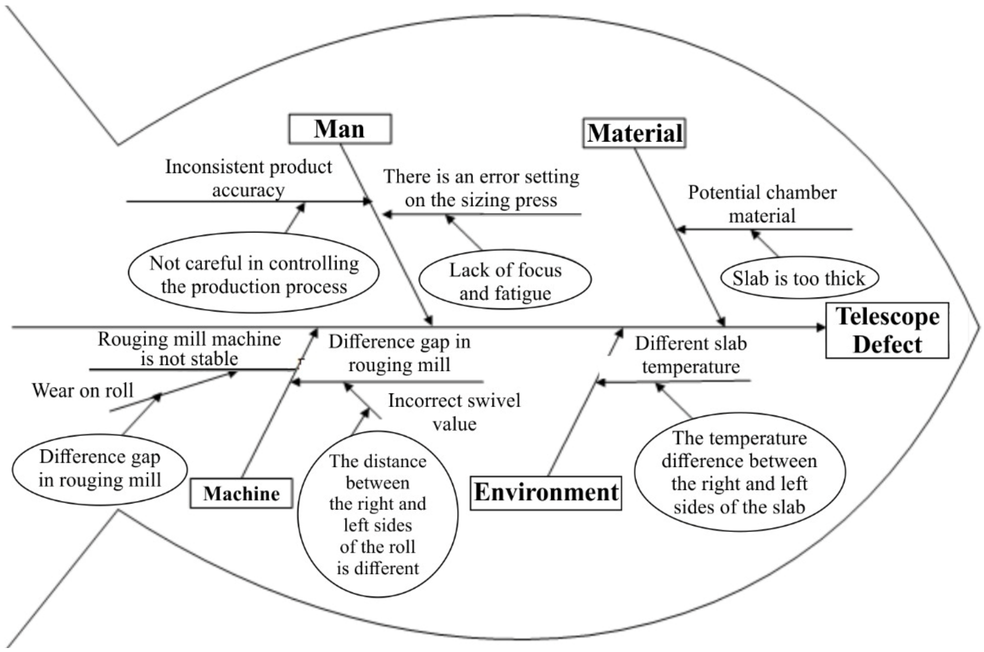

Figure 4. Fishbone Diagram of Telescope Defect

The causes of telescope defects can be seen in the image above, which include the human factor, such as the operator's lack of focus and fatigue, which results in an error in setting the sizing press, as well as the operator's inaccuracy in controlling the production process, which results in inconsistent product accuracy. The material has the potential to be a chamber due to material considerations, such as a slab that is excessively thick. The variation in temperature on the right and left sides of the slab results in varying slab temperatures due to external influences. On the machine factor, the right and left sides of the roll are separated by a different distance, resulting in an inaccurate swivel value and a different gap in the rouging mill. Furthermore, wear and tear on the roll renders the machine unstable, resulting in a rouging mill machine that is unstable.

2) Wavy Defects Fishbone Diagram

The fishbone diagram below depicts wavy faults or corrugated steel defects that occurred at the steel company during HRC is shown in Figure 5.

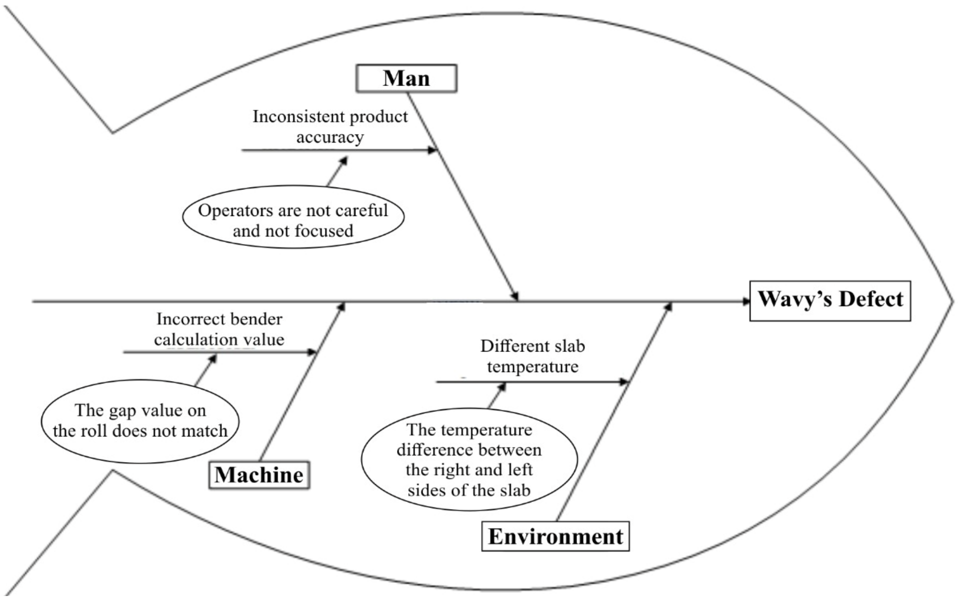

Figure 5. Wavy Defects Fishbone Diagram

The sources of wavy faults may be observed in the image above, which can be seen as a result of the human element, which is created by inconsistent product correctness caused by the operator being less careful and not focusing. It is caused by an inaccurate value of the gap on the roll due to an incorrect calculation value on the bender, according to the machine factor. Different slab temperatures cause a temperature disparity between the right and left sides due to external conditions. Material factors have no bearing on this type of problem.

1) Chamber Defects Fishbone Diagram

A chamber flaw or curved coil defect that occurred during HRC at the steel company is seen in the fishbone diagram below is shown in Figure 6.

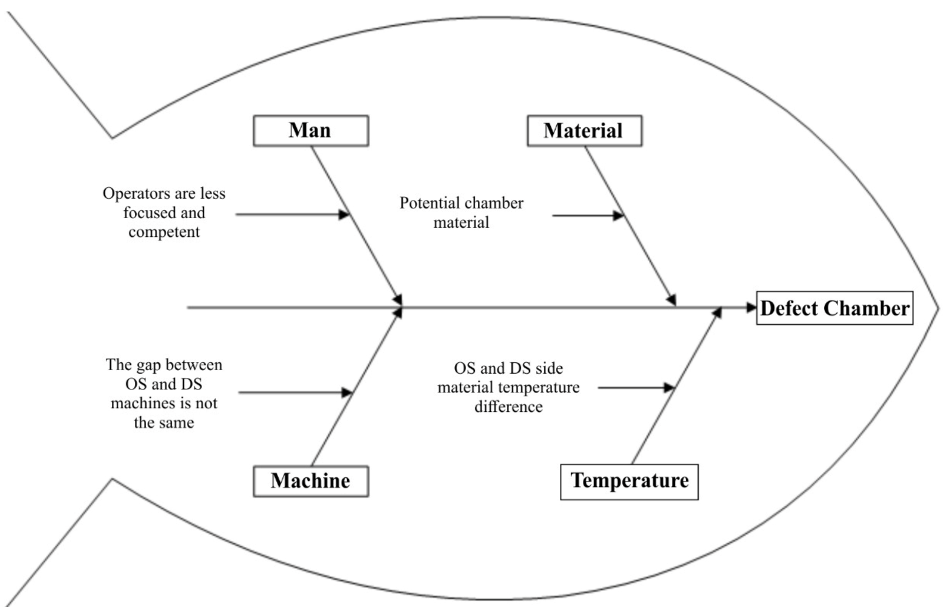

Figure 6. Fishbone Diagram of Defects Chamber

The sources of chamber flaws can be observed in the diagram below, which range from material factors to possible chamber or curved materials. The operator is less attentive and skilled in directing the sizing press because to the human aspect. The slab bends due to a machine factor, specifically the gap between the OS and DS machines, which is out of balance. Finally, there's the temperature factor, which refers to the temperature difference between the OS and DS sides of the material.

3.4. Improve

After determining the cause of damage and the types of product faults that occur, the improvement step involves putting forward plans in the form of suggestions for improvement in order to improve the quality of the final product. The following is a proposed enhancement to the HRC product of the steel company's HSM division to eliminate the types of telescope, wavy, and chamber flaws (Shown in Table 5, 6, and 7).

Table 5. Proposed Telescope Error Corrections

Factors	Causing	Improvement Proposal
Material	The slab is too thick	Reduce the use of slab ripping
Man	Lack of focus and fatigue Not careful in controlling the production process	We are monitoring employees to work according to predetermined standards. Conduct regular or ongoing training to motivate work morale and provide bonuses or incentives for outstanding employees.
Machine	The distance between the right and left sides of the roll is different Wear on roll	Optimizing the loading plant. Carry out regular checks and periodic repairs to avoid delays in replacing worn rolls.
Environment	The temperature of the right and left sides of the slab is different	Settings on the water descaler so that the temperature remains the same and balanced.

Table 6. Fix on Wavy Defect

Factors	Causing	Improvement Proposal
Man	Lack of focus and fatigue	We are monitoring employees to work according to predetermined standards.
Machine	The gap value on the roll does not match	Improve supervision of work roll grinding results in RTS.
Environment	The temperature of the right and left sides of the slab is different	Settings on the water descaler so that the temperature remains the same and balanced.

Table 7. Proposed Improvements to Chamber Defects

Factors	Causing	Improvement Proposal
Material	Potential chamber material	Setting on the slab ripping process.
Man	Operators are less focused and competent	We are monitoring employees to work according to predetermined standards.
Machine	Gap between OS, and DS machines is not the same	Improve supervision of work roll grinding results in RTS.
Environment	Difference in OS and DS side material temperature.	Maintaining the production line so that the slab that is always heated can be processed directly so that the temperature does not decrease quickly.

4. Conclusion

Conclusions can be drawn from the research results and analysis of defects in HRC products in the HSM division at an Indonesia's largest steel company. Namely, in HRC products, there are 37 types of defects. The types of defects in HRC products that often occur during one year of production are telescope defects, defects, and chamber defects. The HRC product of the HSMPT steel company division is in a condition of sigma level 3 where it is still very far from zero defect, namely sigma level 6.

Based on the data above, there are several factors that cause telescope, wavy, and chamber defects, namely humans, machines, materials, and the environment. Proposed improvements that can be made in reducing telescope-type defects are reducing the use of slab ripping, monitoring employees, and setting the water descaler so that the temperature remains balanced—as for wavy type defects, namely conducting regular or continuous training for operators, and increasing supervision of work roll grinding results in RTS. Finally, for the type of chamber defect, namely the setting of the slab ripping process, making SOPs so that there are no operator errors, and maintaining the production line to avoid bottlenecks.

References

Agung, A. W., “Reduksi Waste Dan Perbaikan Penggunaan Energi Pada Proses Produksi Cold Rolled Coil Di PT. Krakatau Steel Dengan Pendekatan Metodologi Lean Six Sigma (Doctoral Dissertation, Institut Teknologi Sepuluh Nopember)”, 2016.

Andiwibowo, R. R., J. Susetyo, and P. Wisnubroto, “Pengendalian Kualitas Produk Kayu Lapis Menggunakan Metode Six Sigma & Kaizen Serta Statistical Quality Control Sebagai Usaha Mengurangi Produk Cacat”, *Jurnal Rekavasi*, vol. 6, no. 2, pp. 100–110, 2018.

Aritonang, S., Bowo, A. H. and Juhana, R,, “Campuran Unsur Adhetive Pada Baja Alloy Sebagai Bahan Dasar Sistem Kekerasan Pelindung Kendaraan Lapis Baja”, *Jurnal Pertahanan & Bela Negara*, vol. 9, no. 2, pp. 81–105, 2019.

Bakti, C. S., & Kartika, H., “Analysis of Ice Cream Product Quality Control With Six Sigma Method”, *Journal of Industrial Engineering & Management Research*, vol. 1, no. 1, pp. 63–69, 2020.

Corder, Anthony S., *Teknik Manajemen Pemeliharaan*, Erlangga, Jakarta, 1973.

Fachrur, A. R., and P. D. Karningsih, “Perbaikan Kualitas Wire Rod Steel Di PT. Krakatau Steel (Persero) Tbk. Cilegon Menggunakan Pendekatan Six Sigma”, *Jurnal Studi Manajemen dan Bisnis*, vol. 4, no. 1, pp. 210–23, 2017.

Ganguly, K., “Improvement Process For Rolling Mill Through The DMAIC Six Sigma Approach.” *International Journal for Quality Research*, vol. 6, no. 3, 2012.

Gaspersz, V., *Total Quality Management*, PT Gramedia Pustaka Utama, Jakarta, 2005.

Hani, E., “Pengendalian Kualitas Menggunakan Metode Six Sigma (Studi Kasus Pada PT Diras Concept Sukoharjo)”, *Asian Journal of Innovation and entrepreneurship*, vol. 13, no. 1, 2017.

Montgomery, D.C., *Introduction Ton Statistical Quality Control*. 3rd ed, John Willey & Sons, Canada, 1996.

Nakhai, Behnam, and Joao S. N., “The Challenges of Six Sigma in Improving Service Quality”, *International Journal of Quality & Reliability Management*, vol. 26, no. 7, 2009.

Nugroho, A., and L. H. Kusumah, “Analisis Pelaksanaan Quality Control Untuk Mengurangi Defect Produk Di Perusahaan Pengolahan Daging Sapi Wagyu Dengan Pendekatan Six Sigma”, *Jurnal Manajemen Teknologi* vol. 20, no. 1, pp. 56–78, 2021.

Prawirosentono, S., *Filosofi Baru Tentang Manajemen Mutu Terpadu Abad 21: Studi Kasus Dan Analisis*, Bumi Aksara, Jakarta, 2002.

Purnama, Jaka, Suparto, and Christa P. D., “Peningkatan Produktivitas Dengan Implementasi Metode Six Sigma Pada Produk Element Boiler”, *Jurnal SimanteC*, vol. 5, pp. 123–32, 2016.

Regan, R., *Process Improvements, Measures Dan Metrics, The Product Of Lean Six Sigma*, BPTrends, 2012.

Safrizal, M., “Pengendalian Kualitas Dengan Metode Six Sigma”, *Jurnal Manajemen dan Keuangan*, vol. 5, no. 2, 2016.

Sav, A. H., “Usulan Perbaikan Untuk Menurunkan Aktivitas Rework Pada Kabinet Upright Piano Pwh Menggunakan Metode Six Sigma Dan Fmea (Failure Mode And Effect Analysis) (Studi Kasus: Sanding Small UP PT. Yamaha Indonesia)”, 2018.

Savitri, A., *Revolusi Industri 4.0: Mengubah Tantangan Menjadi Peluang Di Era Disrupsi 4.0*, Genesis, 2019.

Soemohadiwidjojo, A. T., *Six Sigma Metode Pengukuran Kinerja Perusahaan Berbasis Statistik*, Raih Asa Sukses, 2017.

Wulansari, R. E., Khasanah, A. F., & Djunaidi, M., “Analisis Pengendalian Kualitas Ukuran Partikel Broiler 1 Dengan Metode SPC (Statistical Processing Control)”, *IENACO (Industrial Engineering National Conference)*, vol. 8, 2020.

Zasadzien, M., “Application of the Six Sigma Method for Improving Maintenance Processes – Case Study”, *ICORES*, pp. 314–20, 2017.

Biographies

Arinda Soraya Putri is a lecturer at Industrial Engineering Department, Universitas Muhammadiyah Surakarta, Surakarta, Indonesia. She obtained her Masters of Industrial Engineering and a Bachelor of Engineering in Industrial

Engineering from Universitas Sebelas Maret, Surakarta, Indonesia. She is a member of the research group of Logistics and Industrial Optimization from 2019 until now. Her research interests are Logistics & Supply Chain Management, Distribution Systems, Simulation, Market Testing Analysis, and Feasibility Study.

Husen Riza is an undergraduate student of the Industrial Engineering Department of Universitas Muhammadiyah Surakarta, Surakarta, Indonesia. Her research interests are in the Quality Control, Green Quality Function Deployment, and Production Process.

Agung Pamungkas is a graduate student of the Industrial Engineering Department of Universitas Sebelas Maret, Surakarta, Indonesia. Her research interests are in the Product Design, Ergonomic, Biomedical and Production Process.