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Optimizing the clinker production by using an automation model in raw material feed

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ABSTRACT

The clinker production process involves much equipment and material flow; thus, an operating system is needed to regulate and manage the production process. XYZ company uses an operating system for clinker production called Cement Management Quality (CMQ). The CMQ operation on clinker production is considered semi-automatic because it requires many interventions from the operator. Furthermore, the program is limited under specific condition. As a result, the quality of the clinker is decreased, and the energy consumption is increased. The failure of clinker production is related to the CMQ system, and it is vital to solving the problem appropriately. Since the CMQ system is connected with many aspects, it is essential to find the root cause. Root Cause Analysis (RCA) method is suitable to find the root of the problem for a complex system. After researching using RCA, the main problems on the CMQ system is the data not appropriately integrated, and the process algorithm is insufficient. The new integration of data transfer and new algorithms are developed as an attempt to solve the issues. The new data integration model and algorithm are applied through the simulation method as a test case before taking complete corrective action on the CMQ system. The new model's application shows the standard deviation of the process is decreased under the specified threshold. The method provides good results for improving the quality of the clinker production process. It can be used as an essential reference for applying the automation model in the clinker production process.

1. Introduction

Cement is the primary material for developing infrastructure and building. The need for cement tends to increase linearly as global development increases; therefore, cement production is a good business opportunity. Besides the quantity of production, the quality of the cement is also needed to be maintained and improved as well.

Clinker is the primary raw material for cement production. Clinker is a compound formed from limestone, clay, siltstone, and iron sand. All the raw materials are burned through the kiln unit to react and formed a clinker. The combustion process on the kiln unit is done at high temperatures causes the cement production process is positively related to increased energy consumption. The value of the quality of clinker production is indicated by the standard deviation for each raw material and the energy consumption used per quantity of production (STEC).

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A case study at XYZ company shows that the quality of clinker production has decreased, and energy consumption has increased significantly. The losses of the clinker production from 2017 – 2019 are summarized in Table 1.

Table 1. Losses in clinker production in XYZ company from 2017 – 2019

Year	Clinker Losses (Billion IDR)	Energy Losses (Billion IDR)	Total Losses (Billion IDR)
2017	9.75	3.74	13.49
2018	3.95	1.52	5.47
2019	7.03	2.70	9.73

The losses in Table 1 are caused by the low quality of the clinker produced. The decrease in clinker production affects the increased energy consumption, decreased the clinker's quality, and made the production cost increase while the quality reduces. Table 2 shows the average clinker production quality derived from the standard deviation of raw materials and Specific Thermal Energy Consumption (STEC).

Table 2. Report on the achievement of clinker production quality at XYZ company from 2017 – 2019

Unit	Indicator	Target	Achievement		
			2017	2018	2019
raw mill	σLSF (short)	< 3.6	5.54	4.33	3.69
	σSR	<0.03	0.09	0.09	0.07
	σAR	<0.03	0.22	0.10	0.09
kiln feed	σLSF (short)	< 1.2	2.54	1.74	2.17
	σSR	< 0.03	0.05	0.05	0.06
	σAR	< 0.03	0.06	0.06	0.06
clinker	Cli LSF	< 1.2	1.74	1.45	1.8
stec	MJ/t-cli	3,462	3,656	3,614	3.657

The high standard deviation of raw materials and Cli LSF are caused by the increased standard deviation in the raw mill unit. The high standard deviation in raw mill is caused by an unstable supply of raw material and makes the raw mill process ineffective. The low quality of material supply from raw mill units affects the next process in the kiln unit. The raw material's reaction in kiln feed will be challenging, and the energy for the combustion will increase significantly. The low reaction rates of raw meal in kiln feed resulting in high Cli LSF.

The raw meal preparation is managed and controlled by an operating system called Cement Management Quality (CMQ). The process runs in semi-automatically mode because it depends on the operator's ability to adjust the data input in the system. The drawback is the fluctuation in the process and varies from one operator to another. The optimization of clinker production provides many advantages. Wurzinger et al. (2019) show a positive result on the optimization in clinker production by using an automatic process and make the energy required for clinker production decrease significantly while maintaining clinker quality. An automated system application to the rotary kiln using a cyclone preheater and clinker cooler model can reduce energy consumption for clinker production and maintain good clinker quality. Even though the automated system application in clinker production shows good results, the efforts were carried out by changing many aspects in the system and focused on improving the machine, which means that the material and operator aspects were not considered the optimization process. It can be considered that the root of the problem in the production system has not been fully resolved.

Implementing the automation system in clinker production must also consider the aspects of material characteristics and human force. It is necessary to make superior modeling for the overall system improvement. In the transition process from a semi-automatic system to a fully automatic system, the control cycle process of production planning needs to be made in a model based on the existing model in the company. Figure 1 shows an outline of the production planning control cycle in manufacturing.

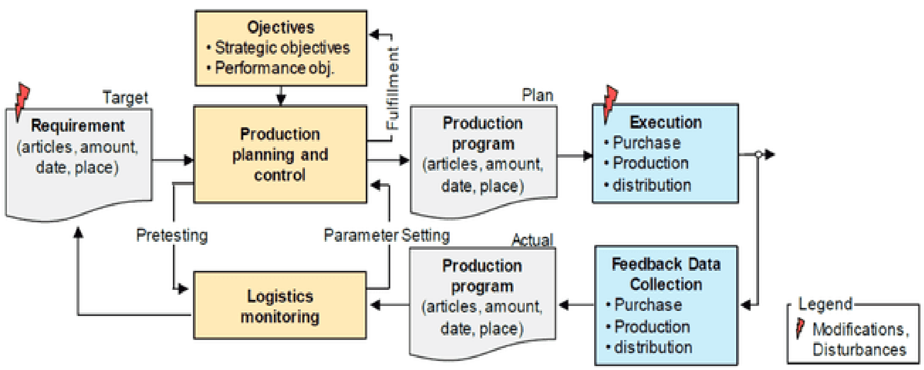

Figure 1. The model of production planning control flow

The optimization of clinker production from previous research is focused on the machine aspect and change much equipment that requires high cost. Another consideration is that the previous study's primary variable is considered constant, wherein the actual process of the variable in the clinker production is always changing. Overall, the optimization effort from the previous study is lacks feasibility. Implementing an automation system must pay attention to all aspects of the production process, especially for the clinker production process, which involves many material flows, energy, and working operators.

This research's main objective is to understand the transition process of applying the automation concept to the clinker production process. The preliminary study before the solution implementation is carried out by conducting an in-depth analysis of problems in the system. The study of the problem is further analyzed to find all aspects are involved. Once the solution model is proposed, the automation model concept is tested first through modeling to determine the effectiveness of the new model. The new model implementation results are used as a reference for further consideration regarding changes in the production system. The method can be used as a reference for the transition from semi-automatic to automatic systems without making significant changes to the operating system and achieving good feasibility for significant changes in the system.

2. Literature Review

2.1 Clinker Quality

The clinker production control process is carried out based on quality parameters. A standard indicator of clinker quality is usually based on the amount of free (unreacted) CaO from the sample drawn. It affects the mechanical strength of the cement. The indicator is influenced by the clinker quality parameters, which consist of:

a. Lime saturation factor (LSF)
b. Silica Ratio (SR)
c. Alumina Ratio (AR).

The control model based on Proportional Integral Derivative (PID) between the chemical modulus at the Raw Meal output and the proportion of raw material in the mill feed is used as the optimization criterion for the minimum standard deviation in the kiln feed. Stability criteria must be applied to maintain clinker quality and the effectiveness of the production process. The variation in kiln feed composition depends not only on the variation of the raw material and the maximum capacity of the mixing process in the silo but also on the effectiveness of the production process's measures.

2.2 Automation Concept on a Production System

The application of an automation system to the production system has become necessary in the industrial era 4.0. The idea of industry 4.0 is a high–promising approach because it integrates business and manufacturing processes and integrates all actors in the company value chain (suppliers and customers). The requirement's technical aspect is to use the generic concept of Cyber-Physical Systems (CPS) and the industrial Internet of Things (IoT) in the production systems.

Production process planning and control processes involve all activities, including scheduling, capacity, and quantity-based planning and control. On the other hand, the system design process involves modeling, analysis steps, synthesis, and optimization. The primary key is to understand the system design's pattern and purpose by considering all involved parameters and variables.

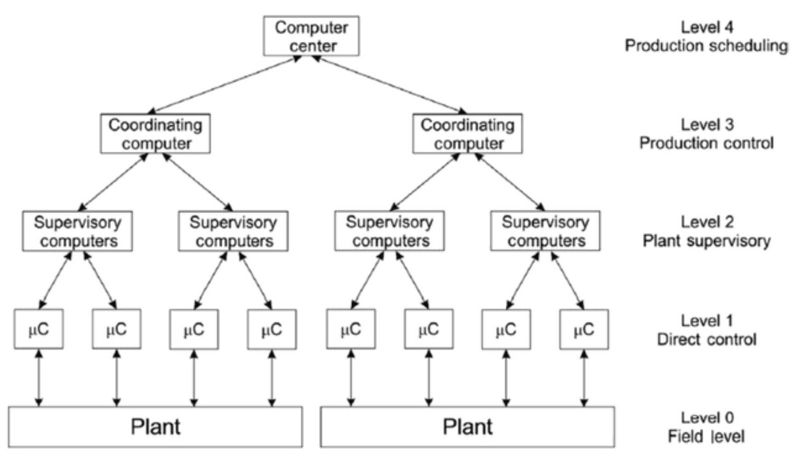

Figure 2. Functional levels of manufacturing control operation

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2.3 Cyber-Physical Production System

The production system is an integrated system that involves the physical and digital world. The CMQ system was used in the clinker production process at XYZ company refers to cyber-physical production systems because the physics and digital aspects are involved in the process. Efforts to strengthen the production system is by maximizing the production process based on specific steps and studies. Transition and re-strengthening the production system by combining physical and cyber aspects are carried out based on the appropriate process flow to maximize the expected results. The flowchart model for the Cyber-Physical Production System (CPPS) can refer to Figure 3.

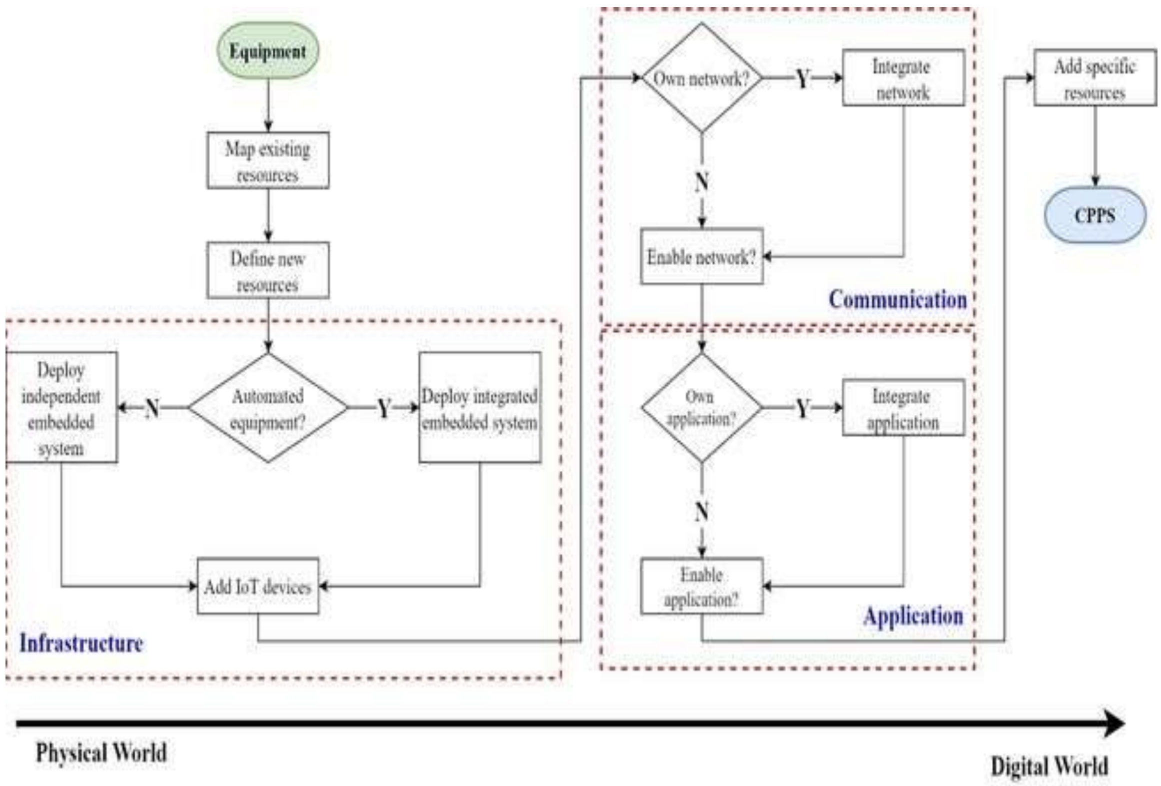

Figure 3. CPPS Retrofitting process flowchart

3. Research Methodology

Optimization of the clinker production process through the application of the automation concept must consider the operating system's characteristics and the completeness of the products used. The clinker production system, which is very complicated and involves many variables, causes many aspects to apply to the automation concept. The suitable method for this case is to use the Root Cause Analysis method. The Root Cause Analysis method consists of seven steps that are carried out in a sequence. The seven steps in the Root Cause Analysis method are in Figure 4.

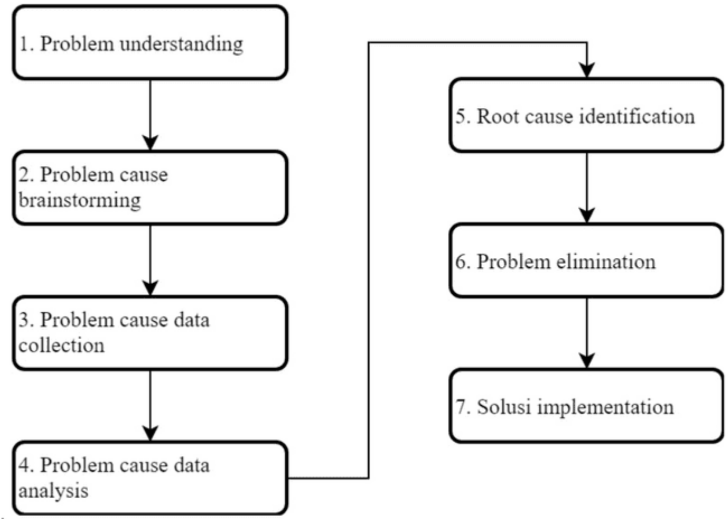

Figure 4. Step by step root cause analysis

A detailed explanation of the steps in root cause analysis is:

1. Problem understanding is the process of understanding the problems that cause low-quality clinker production. This study is carried out through the process of collecting data and reports related to clinker production.
2. Problem caused brainstorming is mapping the possible causes of the problem based on the collected data. The model used is a fishbone diagram, which is useful for determining factors that directly affect the clinker production process.

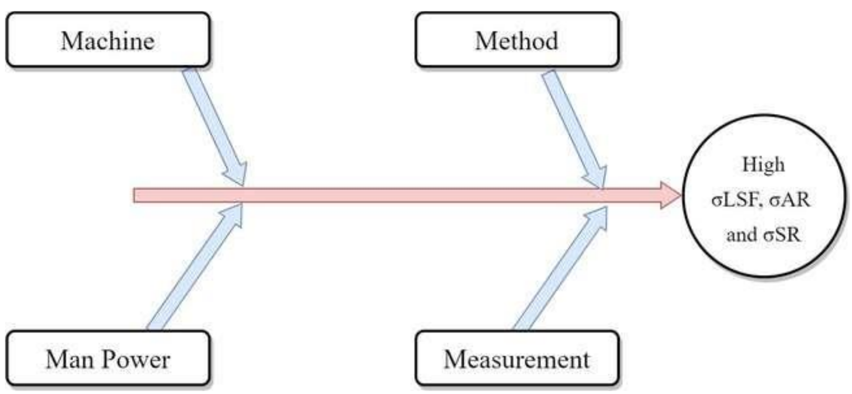

Figure 5. Fishbone diagram on the production process

3. Problem cause data collection, collect actual data related to the mapping results of the possible causes of the problem formulated in the second step.
4. Problem cause data analysis is a specific analysis regarding the results of the actual data collection on the possible causes of the mapped problem. The output is the priority order of the problem. The problem has been formed based on the characteristics of the problem mapped based on the latest data.

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5. Root cause identification is a step taken to identify the leading causes of the problem based on a more comprehensive study related to actual data and analyses from the team in charge. In this section, the influencing factors have become more specific. The model of the fishbone diagram in this step is shown in Figure 6.

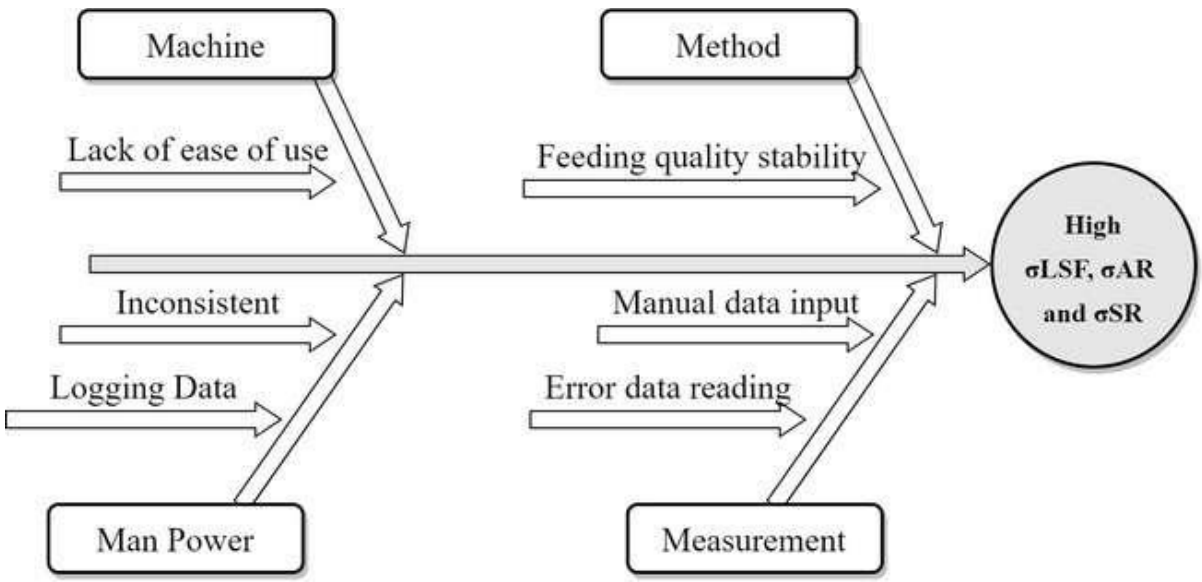

Figure 6. Final diagram fishbone of the effect on high σLSF, σAR dan σSR

6. Problem elimination, the stage where the causes identified in the final fishbone diagram are eliminated. The elimination process was carried out using standard procedures from the Failure Method and Effect Analysis. Problems with the highest Risk Priority Number value were chosen as the root cause. The analysis results show that the highest risk priority problem is related to the computer operating system (CMQ) used for the clinker production process.
7. Solution implementation is the stage of implementing corrective actions based on the root cause determined in step 6. The corrective action process is adjusted based on the nature of the problem. The adjustment is carried out by creating the corrective action team. The team formation consists of all departments related to the production process. In the case of a CMQ system, standard project management processes are used to make the team's improvements.

4. Results and Discussion

4.1 Basic CMQ Flowchart

The critical problem is that the CMQ system is not optimal and impacts the production process. Systems that work using software work in a specific order, so the effort to improve the CMQ system that needs to be done first is to understand the system's work flowchart in the clinker production process. Figure 7 shows the basic flowchart in a CMQ system.

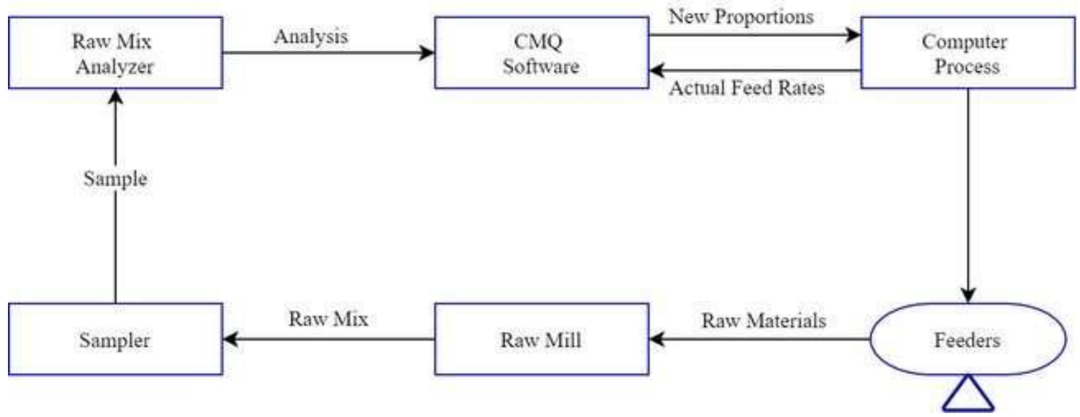

Figure 7. Basic flowchart of the CMQ system

The flowchart in Figure 7 depicts a process made in the series. A sequence of jobs requires that the previous task be completed to continue to the next task. The relationship between CMQ software and computer processes in particular is:

a. CMQ software provides information regarding the new proportion of the computer process. This value is used as a reference to determine the proportion value that enters the feeder;
b. Actual feed rates obtained from the feeder's measurement process are used as a reference for the input values in the CMQ software, which are used as the basis for new calculations to determine new proportions.

After the process is complete in the feeder, the raw materials are fed into the raw mill for grinding. Part of the milled product (Raw Mix) is taken for analysis in the lab. The analysis process takes an extended time because the process is still done manually. The data from the lab analysis can only be used to set the next milling process.

As in Figure 7, the processing sequence results in: if a mixture is not suitable or the raw mix value is not as expected, then this result is used as input for the next process. The condition causes an error in the raw mix that has been processed. It cannot be stopped because the system works continuously. The sample testing process takes a long time. The unsuitable working sequence makes the production parameter's value become unstable and raised the standard deviation of the raw mill. A high standard deviation on raw mill affects the kiln feed process, and then, the standard deviation on KF will increase as well. The high standard deviation of the raw mill and kiln feed directly affects the standard deviation of Cli LSF. The relation between the standard deviation of raw mill, kiln feed, and Cli LSF be seen in Figure 8.

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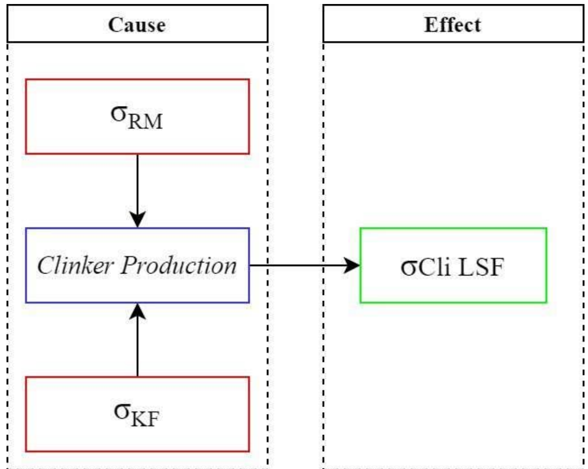
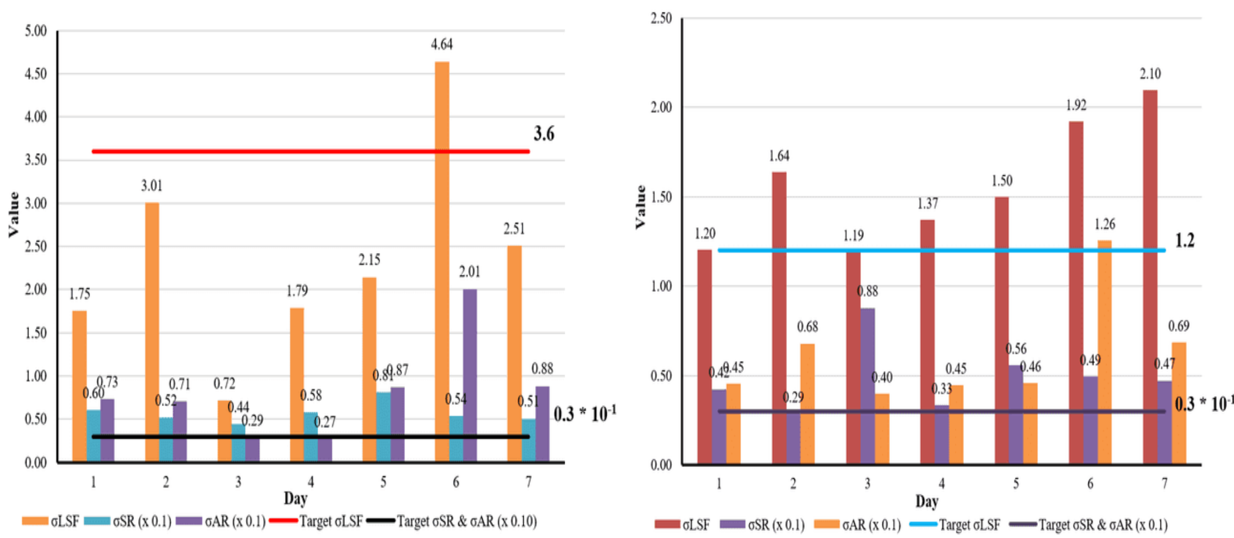


Figure 8. The cause and effect relation of σRM, σKF, and σCli LSF

The relationship model in figure 8 shows that σCli LSF is directly affected by the value of σRM and σKF. To see this relationship clearly, the production report from the last seven days before it takes corrective action is presented in Figures 9a and 9b (for σRM and σKF) and Figure 10 (for σCli LSF).



(a) (b)

Figure 9. Data for σRM (A) and σKF (B) before solution implementation

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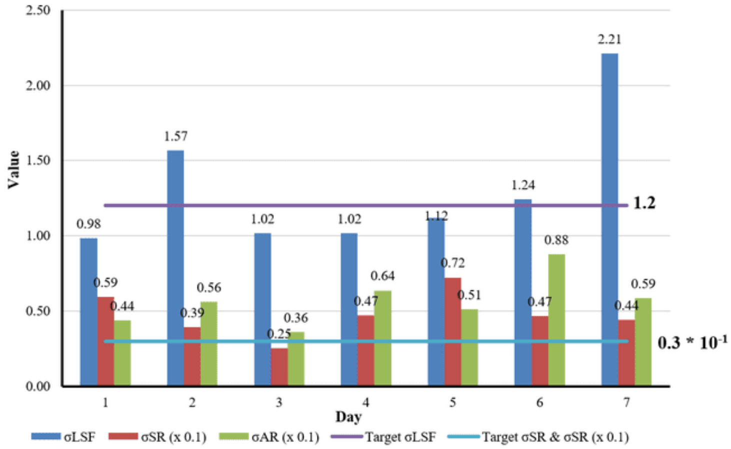

Figure 10. Data for σCli LSF before solution implementation

The data in Figures 9 and 10 clearly show the relationship between the increase in the standard deviation of σRM and σKF, increasing σCli LSF. The basis of the problem occurs because the CMQ work system is inadequate, which increases σRM, then directly affects the σKF, and both affect the σCli LSF.

4.2 Modeling the solution

The corrective team conducts a study that expressly creates a model and formulates the root of the CMQ system's problem. The results of the research are two essential ideas that can be used as solutions. The ideas are:

a. The CMQ software has many limitations, so it is necessary to adjust the algorithm model of the software;
b. The work sequences of the CMQ system are modified.

Due to limited time for corrective action, the complete modification of software through reprogramming may not be sufficient. Because of the RCA method, the team can carry out further analysis to determine possible solutions based on the existing problems' characteristics, so the first proposed idea can be said as a wrong idea for the leading solution related to the CMQ system improvement. The team chose the second option, which could be done considering that the work sequence can be simulated first before changing the program on the whole system.

Modeling solutions to repair work sequences is carried out using integrated computer systems (LAN and WLAN). The selection of an integrated system using LAN and WLAN networks makes it easy to simulate the work sequence without changing many existing production equipment. The integration model map is made based on the relationship between the production process and the production process indicators, namely the value of σLSF, σSR, and σAR. The developed integration model is shown in Figure 11.

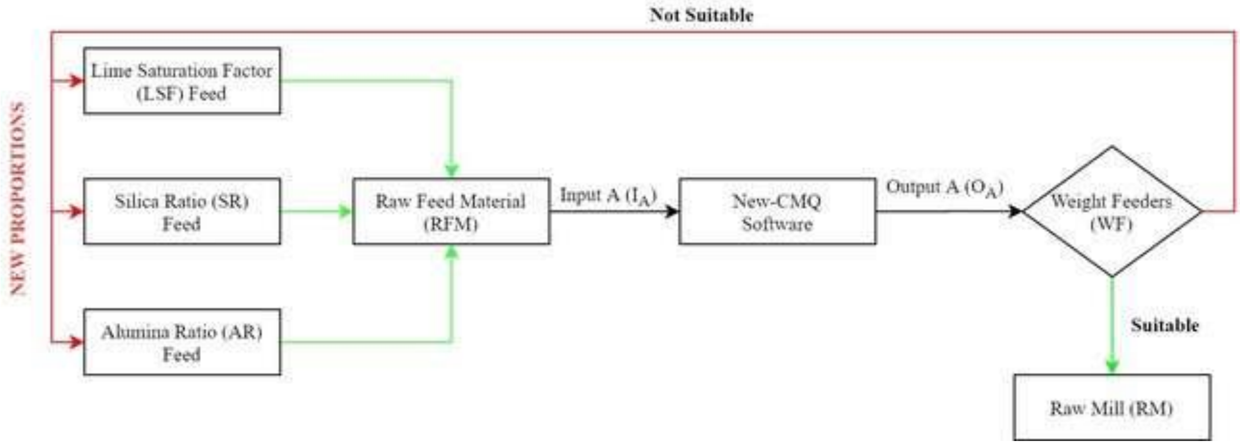

Figure 11. New adjustment for data integration in CMQ system

The values of σLSF, σSR, and σAR are the most important indicators used as the references for material input. The values are used to determine the amount of raw feed material to be processed. When the raw feed material value has been determined, it is used as input to the "New–CMQ" model. The new value in "new–CMQ" is used to set value for the weight feeder. Weight feeders determine whether the process can be continued or not. When the predetermined values do not match, the weight feeders will send a signal to readjust the values of σLSF, σSR, and σAR. When all the values are correct, the new material can be processed to the Raw Mill.

Integrated data adjusted based on the CMQ system in Figure 11 is used as a model to determine the system's work order. The basic flowchart on CMQ requires the new samples to be tested after the grinding process. Based on the latest adjustments, the CMQ system's flowchart is adjusted based on the existing sequence. The new flowchart on the "new–CMQ" is shown in Figure 12.

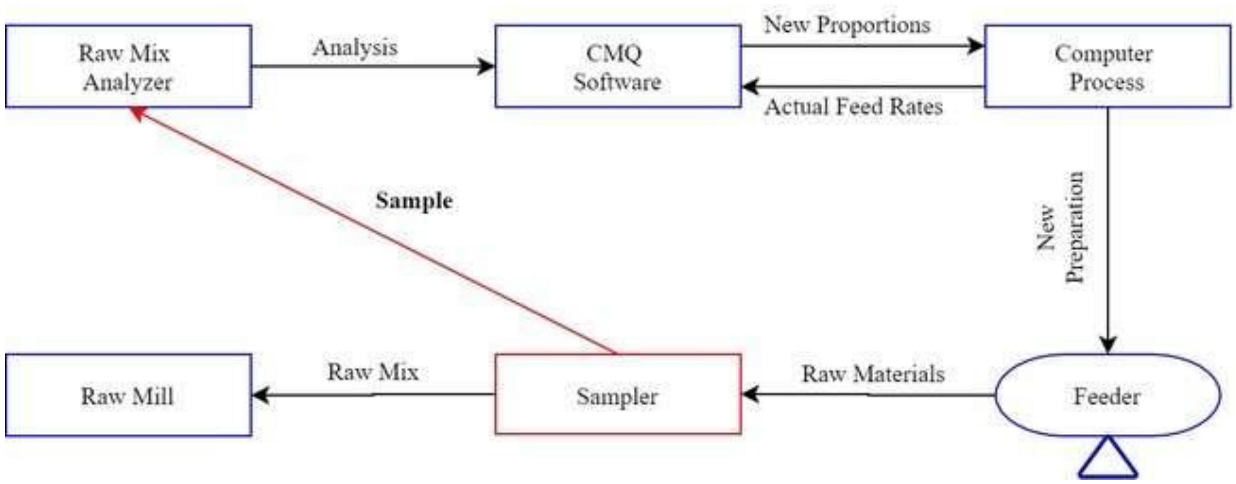

Figure 12. New flowchart for CMQ system after new adjustment for data integration

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The primary key that has been changed based on the basic CMQ flowchart is the sampling process. In the new–CMQ model, samples are taken after the feeder before entering the raw mill process. It provides an opportunity to determine the material's quality to be processed whether it is suitable or not. New adjustments for data integration and improvements to the order of work have a strong relationship. Reading the sample on the Raw Mix Analyzer is used as the raw meal's decision value to be milled. The integrated system allows for faster sample reading, and the decision-making process can be done accurately.

4.3 Testing the new flowchart on the based on New–CMQ model

The new adjustments for data integration and work order in the raw meal preparation process are tested to determine the results of the changes in the clinker production process. The test was carried out for three days as an initial test case. Figures 13a and Figure 13b show the σRM and σKF.

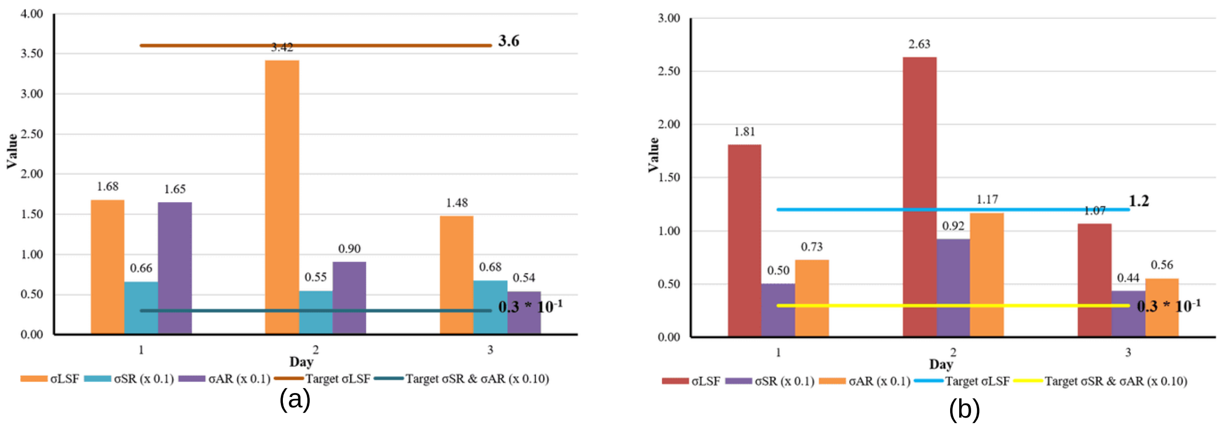

Figure 13. Data for σRM (A) and σKF (B) after solution implementation

There are differences in the test results' performance for the new work sequence model in the system. A clear difference can be seen when the value of the process parameter (σLSF) at RM is under the maximum allowance target, while σLSF in KF exceeds the specified limit. The importance of σSR and σAR in both of them still exceed the target limit.

The most significant result is shown in the value of σLSF for RM, which able under the maximum limit. The new adjustment in the new–CMQ for data integration and working sequence is specifically designed to adjust the Raw Mill's material flow. In general, the application of the new working sequences and data integration in the new–CMQ system shows a positive impact on the value of σLSF in RM. The values of σSR and σAR still exceed the threshold because it related to the material (limestone, clay, siltstone, and iron sand), which have a more dominant influence on the values of σSR and σAR.

The σLSF, σSR, and σAR in kiln feed are generally still above the specified limit. The main reason is that the kiln feed indicators are related to another factor besides the raw meal. The combustion process and coating behavior in the kiln unit also influence the production parameters in kiln feed. Although there is an influence from external factors, there is a relationship between the value of σLSF on raw mill and kiln feed. The decrease in the value of σLSF in the raw mill also impacts the reduction in σLSF in KF. It can be seen in the experiment on the third day, where the σLSF value in RM could reach the lowest point of the test for three days, and the σLSF value on KF could fall below the set target. The σCli LSF shows a better result during the trial of the new CMQ system. The result of the σCli LSF during the test are shown in Figure 14.

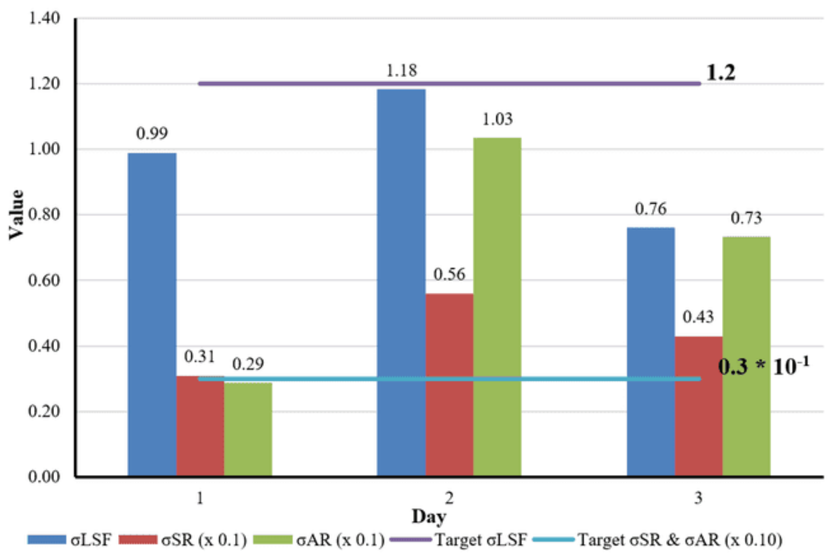

Figure 1. Data for σRM (A) and σKF (B) after solution implementation

The σLSF on three days along the new CMQ system trial has decreased significantly and can fall below the specified limit. It is a good indicator for clinker production, and it can be seen that the changes in the parameters at raw mill and kiln feed can reduce the σCli LSF. In particular, the low value of σLSF at raw mail impacts the σLSF in the clinker. The most important influence on the Cli LSF is from the raw mill unit. It is the main reason why even the σLSF in kiln feed is still above the specified threshold. The σLSF value in the clinker can decrease significantly.

5. Conclusion

Efforts have been made to optimize the clinker production process through the application of the automation principle. Improvements to the processing sequence and data integration in the CMQ system positively affect clinker production. The concept of automation provides effectiveness in the material preparation that is required for clinker production. The excellent results can be used as a reference in making the automation system through further software development. Also, the cement production process, which is very complex and involves much material and processing at high temperatures, depends not only on the operating system. The combustion process, the kiln unit, the quality of the initial feed material, and the material composition ratio also influence the cement production process. Thus, these conditions can be used as further considerations to develop a broader concept of automation and significantly affect the clinker production process indicators.

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