The planning of iron sand inventory with System Dynamic Approach

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Abstract. The need for iron sand as a supporting material of the cement making is increasing, so companies require planning of inventory control of iron ore to get all the needs in terms of quality and quantity. Inventory control planning will be useful to meet the demand and reduce inventory wastage. In the production process, companies often experience a shortage of materials when demand soared and raw materials excessive when demand decreases. This study aims to determine the best ordering method next year so that the company does not experience the stock shortage. The system dynamics method was applied with the help of Powersim software in terms of modelling and simulating the iron ore ordering system in the form of several scenarios. Based on the result, the best scenario was to order the iron ore as much as 4,013 tons/month, which is twice the amount in the previous policy, and the average inventory of the iron ore was 10,943 tons/month.

1. Introduction

The rapid development of knowledge and technology enables improvement in the industrial sector, such as the iron sand industry. As the natural resources, the cement industry utilizes the iron sand as one of the components in the final products. It is necessary for a company to plan the iron sand raw materials control in terms of quality and quantity because of its high demand as the additional materials for the cement products. Inventory in terms of industry, it is necessary to pay attention to the idle resources for the smooth flow of the production process [1].

The case study is conducted at one of the iron sand industries located at Krueng Raya, Aceh Besar. The company applies the principle of sustainable iron sand in production to meet the fluctuation of the demand. The company faces the problem of inventory shortage when the demand increases and the inventory excess when the demand decreases. The reason for such a situation to occur in the company is because of the inaccurate demand forecast and inappropriate ordering schedule. The fluctuation of the demand shows the figure of customer demand, which is within the range of 2,393 tons to 4,814 tons. In order to solve this problem, a company has to supply the right amount of raw materials. One approach that will assist the company in planning the raw materials is the system dynamics approach, which shows a promising solution for the complex systems. This approach aims to understand the structural and dynamical portion of the complex system and to use that model to lead an effective and subtle organization [2].

There are numerous research studies in the area of inventories and system dynamics, such as to compare inventory models in an automotive [3], to determine safety stock [4], to reduce total inventory cost [5] and to improve complex inventory management [6]. Simulation is the practical or
application of the model building step that represents the real system, or the future forecast, or the model experiment by itself, which aims to understand the system, to increase performance, or to design a new system with a designated dimension [7-8]. The predominance of the system dynamics is that the simulation will reduce total cost, time, and energy while preserving nature from the process of trial and error. The simulation process will be using the Powersim software for next year's long inventory planning.

The formulation of the problem in this study is to discover the variables that influence the system behaviour of the ordering numbers and to plan the raw materials with the system dynamics approach. Nevertheless, the simulation of a system dynamics will be showing the behaviour of the system model in terms of both the ordering numbers and the raw materials. The result of the simulation is the best scenario out of several different scenarios of the raw materials ordering quantity to satisfy the customer's demand.

The goal of this study is to observe the behaviour of the system in terms of the ordering numbers and the raw materials with Causal Loop Diagram (CLD) model and to decide the behaviour of the system in terms of the company's ordering quantity and inventory with Stock Flow Diagram (SFD) model. The result gave several scenarios of the raw materials ordering quantity that will comply with the demand from the customers. Therefore, this study consists of the modelling and the system dynamics simulation for obtaining the best scenario of inventory planning and raw materials ordering to avoid the inventory shortage situation.

2. Method
The simulation process includes several steps to solve the complexity of the models, i.e. [9]: formulation of the problems, building the models, data acquisition, transferring the models and formulations, verification, validation, the tactical and strategic planning, experiment, result in analysis, and implementation and documentation.

Firstly, it is necessary to identify the problems at the company to find the object of the study. Finding the object of the study, then the next step is further study regarding the solutions to the problems. The next step is to collect the appropriate data with the problems. There were two different data collection methods in this study, namely the primary and the secondary data. The primary data was the result of brainstorming with an expert to discover the problematic variable, which would be used as the structural system of the models for the CLD and SFD. The utility of secondary data was to develop the SFD models for simulation according to the problem in the company. The data included the iron sand demand, the iron sand inventory, and the utility of iron ore.

The next step was data processing. Data processing software called Powersim was used to process the data. There are three different parts of the data processing, i.e. CLD, SFD, and scenario simulation. There are three steps for processing the CLD. The first one is the preliminary CLD that is using the model from previous research. The second one is the model development into working CLD based on the problems at the company and the knowledge from experts. Before the final stage, it is necessary to brainstorm the model with experts. Finally, the final CLD is ready for the research [10].

For the development of SFD, it is necessary to transform the qualitative translation of CFD to a quantitative one. There are four steps for developing the SFD model [9]. The first step was to build the model structure which connected one component to another using Powersim software. The structure was developed using the logic of the problem; however, to strengthen the research, the development was based on previous research. The next step was inserting the value and formulation for the component of the model. This was the step of transforming the qualitative to quantitative. Verification was necessary to observe the unit consistency of the model. The last stage was to validate the SFD model with the behaviour validity test. Finally, if the model was valid, the scenario simulation could be performed. The best scenario for ordering and inventory management was the scenario that satisfied the overall demand from the customers and minimized the stock shortage in the company.
3. Result and discussion

There are three steps in developing the Causal Loop Diagram (CLD). The first step is to build the preliminary CLD based on the previous research on inventory problems. The second step is to add variables which are the result of brainstorming with stakeholder into the initial CLD for making the working CLD. The stakeholder then will conduct the verification and validation of the model as well as the literature review before finalizing the CLD model [10].

3.1. Preliminary CLD

The model in this research refers to the Business as Usual (BAU) inventory model from previous research by [11]. It is appropriate to use the previous BAU on developing the preliminary CLD. Only the appropriate variables on BAU will be the reference for developing the preliminary CLD; therefore, the selected variables and its connection were appropriate for this research, as presented in Figure 1, as the preliminary CLD. Loop B1 shows iron ore ordering, Loop B2 for iron ore inventory, while Loop B3 for production.

![Figure 1. Preliminary CLD](image)

3.2. Working CLD

The variables on the preliminary CLD was not adequate, therefore, the model required an additional variable for the conceptual model related to the planning of ordering and supplying raw materials. Figure 2 shows the working CLD, while Loop R1 in figure shows production enhancement. Figure 2 shows that the additional variables were related to the production of iron sand. The variables influenced the process of ordering iron sand and the inventory of iron ore. After that, with the help of stakeholder and literature review, the working CLD passed the verification process of structural and relation with the final CLD as a result.
3.3. Final CLD

It is necessary to understand the structure of the modelling system for the accuracy level of the actual model, which represents the real system. The discussion with experts and literature review is necessary to achieve this goal. Two experts contribute their knowledge to build the model in this research.

The final CLD (figure 3) shows that there were two other variables which influenced the ordering of iron ore besides the iron ore inventory and the iron ore reception. The other variables were the reorder point and safety stock. The final CLD consisted of four different loops, and three of which were balancing loops and the other was a reinforced loop.

3.4. The SFD construction

The stock and flow diagram is more complicated than the causal loop diagram. It is necessary to have several sub-models to simplify the process of understanding and building the model. There were two sub-models in this research, i.e. the sub-model of the production process (Fig. 4) and the sub-model of ordering raw materials (Fig. 5). The final model required a combination of the two sub-models. The problem logic in building the SFD model refers to [12].
There were several modifications to the model structure, variables relations, and variable constraints to build the SFD of the production process sub-models. The whole process of building the primary model of the production process was based on previous research with the same production process concept. The variables of production and sale quantity are the two main variables in determining the production process.

On the other hand, the building process of the raw materials ordering sub-model refers to the past research, the general logic of raw materials order, and the actual condition of the company. There were four significant variables which influenced the iron ore order process, i.e. the iron ore inventory level which relates to the iron ore reception, the iron ore utilization which was converted to the daily unit, the raw material in order which is part of the iron ore ordering and reception process, and the stock of first and second supplier which means the capacity of supplying the iron ore to the company.
Figure 6 shows the combination of the production process sub-model and the raw materials ordering sub-model. This is the SFD main model in this research.

![Figure 6. SFD main model](image)

3.5. *Simulation of the existing condition*

Based on the SFD model, the simulation started with the existing condition and the alternative scenarios has not yet been considered. Figure 7 shows the time graph as the simulation result of the real situation. Figure 8 shows that the company will always experience the stock shortage for the next several years. This situation occurs because of the higher number of iron ore demand than the iron ore production quantity.

![Figure 7. Time graph of production quantity](image)
3.6. Verification
The CLD was verified after the theoretical verification and brainstorming with the company staff members. The reason is that, in the real system, the higher reception of iron ore equal to the higher inventory of iron ore. Therefore, the theoretical verification shows that there was no difference between the real situation and the CLD model in terms of the relationship between iron ore reception and inventory. On the other hand, the process of the SFD model verification requires the simulation test without demand, and the initial inventory was 350 tons.

In this research, the daily demand, the quotidian demand result, iron ore utilization, and iron ore production quantity were zero ton; and the inventory was the same as the initial stock, i.e. 350 tons. The test result shows that there was no obstacle in the simulation, which means that the SFD model was verified.

3.7. Validation
The validation process is necessary to find out whether the model simulation is valid with no error, and it is for comparing the structural model behaviour with the real situation. After the validation process, then the model is appropriate to represent the situation in the company. In this research, the validation process was performed using the behaviour validity test, which was based on historical data. Table 1 shows the historical data test result.

The historical data test by comparing the actual iron ore utilization with the simulation one, the mean error was 0.075656 or 7%. The result was lower than 10% with the level of accuracy requirements of 90%. If the validation value is under 10%, with 90% the level of accuracy, then the data is valid.

Figure 8. Time graph of iron ore utilisation
Table 1. Historical data test result

| Month  | Simulation (tons) | Actual (tons) | Errors  |
|--------|------------------|---------------|---------|
| January| 4272             | 4150          | 0.029398|
| February| 4136             | 3226          | 0.282083|
| March  | 4099             | 3980          | 0.029899|
| April  | 4025             | 3587          | 0.122108|
| May    | 4116             | 3789          | 0.086302|
| June   | 4321             | 5079          | 0.149242|
| July   | 4293             | 4197          | 0.022873|
| August | 4256             | 4244          | 0.002828|
| September| 3765             | 4009          | 0.060863|
| October| 3702             | 3570          | 0.036975|
| November| 3894             | 4167          | 0.065515|
| December| 4063             | 4145          | 0.019783|
| Mean   |                  |               | 0.075656|

3.8. Replication Adequacy Test

It is necessary to have the replication adequacy test of the simulation result identification for running the simulation itself. Table 2 shows the replication adequacy test result in the simulation.

Table 2. Replication Adequacy Test Result

| Month     | Iron Ore Utilisation Simulation (tons) |
|-----------|----------------------------------------|
| January   | 4272                                   |
| February  | 4136                                   |
| March     | 4099                                   |
| April     | 4025                                   |
| May       | 4116                                   |
| June      | 4321                                   |
| July      | 4293                                   |
| August    | 4256                                   |
| September | 3765                                   |
| October   | 3702                                   |
| November  | 3894                                   |
| December  | 4063                                   |
| Mean      | 4078                                   |
| Standard Deviation | 203.62                                   |

\[
\text{Half width} = \frac{(2.26 \times 203.62)}{\sqrt{10}} = 145.52 \tag{1}
\]

\[
n' = \left(\frac{1.96 \times 203.62}{145.52}\right)^2 = (2.742)^2 = 7,521 \approx 8 \text{ replication times} \tag{2}
\]

The calculation result shows that it requires at least eight replication times of the data replication test for the valid simulation result. This research consisted of 10 replication times, so the replication
time for simulation was adequate. After the replication adequacy test, the next step was to simulate with alternative scenarios to get the best scenario for raw materials ordering policy that satisfies the iron sand demand.

3.9. Scenario simulation

The model aims to determine the raw material ordering quantity, which is more than the mean utilization of iron ore. There were three scenarios in this research, i.e. the ordering quantity of 1.5 times the previous amount, the ordering quantity of 1.75 times the previous quantity, and the ordering quantity of two times the previous quantity. Table 3 shows the simulation test results in several scenarios.

| Scenario | Average Ordering Quantity (Ton/month) | Average Inventory (Ton/Month) | Average Stock Shortage (Ton/Month) |
|----------|--------------------------------------|------------------------------|----------------------------------|
| I        | 3521                                 | 6217                         | 151                              |
| II       | 3916                                 | 9628                         | 75                               |
| III      | 4013                                 | 10943                        | 0                                |

The determination of the best result requires the understanding of planning and ordering the raw materials for the result without a stock shortage. In the scenario I, the ordering quantity of 1.5 times more than the previous amount had the average ordering quantity of 3521 tons/month and average inventory of 6217 tons/month while it experienced the stock shortage with an average of 151 tons/month.

Then for scenario II, the ordering quantity of 1.75 times more than the previous amount had the average ordering quantity of 3916 tons/month and average inventory of 6217 tons/month while the stock shortage was 75 tons/month in average. However, in scenario III, the ordering quantity of two times more than the previous amount had the average ordering quantity of 4013 tons/month and an average inventory of 10943 tons/month without the stock shortage.

Therefore, based on these three scenarios, the best scenario was scenario III with the ordering quantity of 4013 tons/month and the average inventory of 10943 tons/month. If the company applies this policy of the iron ore ordering and inventory, the company will minimize the possibility of a stock shortage each month.

4. Conclusion

In conclusion, based on the system dynamics modelling and simulation, the result shows that the best solution was available for raw materials ordering and inventory. The CLD model represented the system behaviour of ordering raw material with several variables which related to each other, and four variable relations in the loop of raw materials ordering and production. The variables include Loop R1 which is production enhancement, Loop B1 which is iron ore ordering, Loop B2 which is iron ore inventory, and Loop B3 which is production.

Moreover, the SFD model, which represents the system behaviour showed the result of Oscillation. Oscillation is the condition of the production quantity which is often not adequate to satisfy the customer demand, in this case, the iron sand demand for each month. As the simulation result, the production quantity was within the range of 30 tons at a minimum and 200 tons as the maximum, and the iron ore utilization was within the range of 30 tons minimum and 240 tons as maximum.

The best scenario for raw materials ordering and inventory was to order two times more than the previous amount with an average quantity of 4.013 tons/month and an average iron ore inventory of 10.943 tons/month. If the company applies this scenario, it will minimize the possibility of the stock shortage each month. However, the company needs to consider additional suppliers to use this scenario.
5. Reference

[1] Andriansyah Sentia P D Elia S E Prasanti N 2018 Decision Making of Inventory System using Monte Carlo Simulation: a study case International Journal of Conceptions on Computing and Information Technology 6 1 5-7

[2] Sterman J D 2000 Systems Thinking and Modelling for a Complex World (USA: The McGraw-Hill Companies, Inc)

[3] Botha A Grobler J Yadavalli V S S 2017 System Dynamics Comparison of Three Inventory Management Models in an Automotive Parts Supply Chain Journal of Transport and Supply Chain Management 11 1-12

[4] Belhajali I and Hachicha W 2013 System Dynamics Simulation to Determine Safety Stock for a Single-Stage Inventory System 2013 International Conference on Advanced Logistics and Transport 488-493

[5] Al-Refaie A Al-Tahat M and Jalham I 2010 A System Dynamics Approach to Reduce Total Inventory Cost in an Airline Fuelling System Proceedings of the World Congress on Engineering 1.

[6] Verwater-Lukszo Z and Christina T S 2015 System-dynamics Modelling to Improve Complex Inventory Management in A Batch-wise Plant Computer Aided Chemical Engineering, 20 1357-1362

[7] Banks J Carson J S and Nelson B L 1996 Discrete-Event System Simulation, 2nd Ed. (Englewood Cliffs: Prentice Hall)

[8] Robinson S 2003 Simulation: The Practice of Model Development and Use (Chichester: Wiley)

[9] Maria A 1997 Introduction to Modelling and Simulation Winter Simulation Conference 7–13.

[10] Qudrat-Ullah H 2012 On the Validation of System Dynamics Type Simulation Models Telecommunication System 51 159–166

[11] Cedillo-Campos M and Sánchez-Ramírez C 2013 Dynamic Self-assessment of Supply Chains Performance: An Emerging Market Approach J. Appl. Res. Technol 11 3 338–347

[12] Japar F Napitupulu H L and Siregar I 2013 Aplikasi Teknik Simulasi untuk Perencanaan Persediaan dan Pemesanan Bahan Baku di PT XYZ [The Implementation of Simulation Technique for Inventory Planning and Raw Material Ordering in PT XYZ] Jurnal Teknik Industri USU 3 4 18–22.