A model for joint decision between production rate and clinker export proportion using cooperative game theory approach

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Abstract. This study aims to provide a decision making model to determine clinker export proportion. Cooperative game theory approach used to build the model. Players in this game are manager of production & material planning, and manager of cement production. Payoff matrix of the game composed using Mixed Integer Linear Programming (MILP) based equation. Expected contribution of this study is to provide a decision making model in determining acceptable proportion between clinker amount to export, and clinker amount to be grinded. Furthermore, this study expected to support revenue maximizing in the company.

1. Introduction
The amount of cement supply and demand in Indonesia has changed since 2015, from an undersupply condition to an oversupply condition. Based on data from the Indonesian Cement Association (ASI), the national cement production capacity currently reaches 113.1 million tons per year. From this capacity, national cement demand is only around 70 million tons per year, so there is an excess production of around 40 million tons per year. Oversupply of cement production in Indonesia is partly due to the entry of foreign cement producers into Indonesia. This condition has forced cement industry to looked at foreign markets to sell their products not only in the form of cement but also clinker.

Figure 1. Cement supply and demand in Indonesia.

As one alternative to obtain revenue, one particular cement company in Indonesia has started clinker exports since 2017, but in that year clinker exports were not yet the focus of the company. Only in 2019 will clinker exports become one of the focuses of the company. Clinker production during low season exceeds the amount needed, while the kiln must operate continuously. Therefore there are times when
the clinker is forced to be placed in open storage. In 2019 kiln 1 and kiln 2 at one plant of one particular cement company in Indonesia was forced to stop for quite a long time (approximately 20 days) due to improper clinker production scheduling during low season. Therefore, aside from being an alternative to obtain revenue, clinker export becomes a crucial thing for cement industry during cement low demand season.

The proportion of clinker exported with clinker to be grinded into cement mill must be calculated appropriately, so that the demand for cement can still be met but not to the point that excess clinker production is stored in open storage. The decision of clinker amount to be exported, the clinker amount to be grinded into cement mill, the kiln and cement mill production rates involved two parties, namely the material & production planning manager and cement production manager. Both parties have common interest and conflicting interest. The common interest is that they both want to contribute to increase company’s revenue. The conflicting interest is that the material & production planning manager wants to export all of the excess from kiln production, whereas the cement production manager wants to use all the clinker produced to be grinded into cement mill. One method that can be used to solve this problem is cooperative game theory. Cooperative game theory can be used because the illustration of the problem that have been explained meets the cooperative game premises, that is involves at least 2 parties, and the benefits are higher when compared to the result from working individually [2].

This paper will propose a model to determine the composition of clinker amount to be exported and clinker amount to be forwarded to cement mill, and also production rates of kiln and cement mill using cooperative game theory, where the payoff matrix is arranged using mixed integer linear programming (MILP), so that optimal revenue associated with the allocation of clinker production can be obtained. The proposed model then demonstrated on one particular cement industry through data experiment.

2. Literature Review
Cooperative game theory is one branch of game theory that models how agents or players compete and work together as a coalition in unstructured interactions to create and capture value [1]. Cooperative game theory is one of mathematical tools developed for the first time by Von Neumann and Morgenstern in 1944. Unlike decision theory where the interests of players are unique or intersect, or zero-sum game where interests between players are opposite, cooperative game theory focuses on situations where mutual benefits occurs between players. One of non-cooperative game example is two person zero sum game, whose equilibrium value is 0, while the example of cooperative game is a two person non-zero sum game.

Research using cooperative game theory approach has been carried out in various fields. Research on human-robot collaborative manufacturing (HRC-Mfg) demonstrated that cooperative game theory can be applied to such system [2]. In another study, cooperative aggregate production planning (Co-APP) introduced as a way to reduce manufacturing plant’s operating costs consisting of production costs, labor and inventory [3]. The principle of Co-APP is that when the production planning of 2 or more facilities/plants are combined, they can exchange labor and product inventory so that product demand can be met at a lower cost. Opportunity for cost savings arise from cooperation between plants, which is from reducing inventory and labor levels. Still in the same study, it was also found that job security and worker satisfaction could increase dramatically with collaboration between plants.

Mixed Integer Linear Programming (MILP) is an Integer Programming (IP) which requires several integer variables, while IP is Linear Programming which requires partial or entire of its variables are non-negative integers [4]. MILP has been widely implemented in various studies. Emir, Guler developed the MILP model to plan production at the cement plant by considering changes in electricity consumption prices [5]. This study shows that the amount of obtained savings when the price of electricity consumption is included in the production plan MILP at the cement plant is 11% in average, even reaching 35% for certain months. The amount of obtained savings will be even greater if factory capacity is less utilized.

The implementation of MILP in scheduling steelmaking-continuous casting production has been investigated also. Several constraints considered in the process scheduling of this study are job grouping,
technological interdependence, no dead time inside the same group of jobs and dynamic processing time of jobs. The study shows that by using MILP at a continuous casting plant, a significant reduction in production time will be obtained [6].

3. Proposed Model

The problem that will be modeled in this paper is how to find a proportion value that can be accepted by both parties, material & production planning manager and cement production manager in this case, regarding the amount of clinker that will be exported and the amount of clinker that will be grinded into cement mill in 1 month. The approach used to model the problems in this paper is cooperative game theory. Payoff matrix of game is arranged using mathematical equations which will be described below. The proposed model is expected to maximize revenue from clinker production at plant owned by one particular cement company in Indonesia. Several assumptions made for proposed model are: exported clinker always absorbed by market, there is always storage space for clinker and cement that made, and no downtime occurred in kiln and finish mill/cement mill. Proposed model in this paper is limited to one particular cement industry in Indonesia.

A player in a game is an entity that makes decisions [7]. The players of the game in this paper are material & production planning manager (referred to as player 1), and cement production manager (referred to as player 2). Both players have common interest and conflicting interests. The common interest is that both players want to contribute to increase company's revenue, whereas the conflicting interests of the two players are as follows:

- Player 1 wants to export all of the excess from kiln production.
- Player 2 wants to use all the clinkers produced.

3.1. Model Indices, Parameters, Decision Variables

Model indices, parameters and decision variables of the model to be formulated are as follows:

Indices

| i  | Kiln; 1, 2, ..., 4 |
| j  | Finish mill/cement mill; 1, 2, 3, ..., 9 |

Parameters

| $O_{KL_i}$ | Kiln $i$ operation time (hour) in 1 month |
| $H_{ECL}$ | Clinker export price ($/ton) |
| $A$ | Proportion of clinker exported (%) to the amount of clinker production in 1 month. Maximum 30% |
| $O_{FM_j}$ | Finish mill/cement mill $j$ operation time (hour) in 1 month |
| $H_S$ | Cement price ($/ton) |
| $P_{Fj}$ | Clinker proportion (%) in finish mill/cement mill $j$ |
| $DS$ | Cement demand (ton) in 1 month |
| $DC$ | An amount of clinker needed (ton) in 1 month to produce cement according to demand |
| $SC$ | Clinker inventory at the beginning of the month |
| $(1-A)$ | Proportion of clinker grinded (%) into finish mill/cement mill to the amount of clinker production in 1 month. Minimum 30% |

Decision Variables

| $P_{KL_i}$ | Production rate (ton/hour) of kiln $i$ |
| $P_{FM_j}$ | Production rate (ton/hour) of finish mill /cement mill $j$ |

3.2. Model Formulation

Formulated model from model indices, parameters, and decision variables described above is shown as follows:
Max \( Z = A\left((\sum_{i=1}^{4} P_{KLi}O_{KLi}) + SC\right)H_{ECL} + \left((\sum_{j=1}^{9} P_{FMj}O_{FMj})H_S\right) \)  

Subject to:

\[ P_{KL1} \geq 320 \]  
\[ P_{KL1} \leq 339 \]  
\[ P_{KL2} \geq 320 \]  
\[ P_{KL2} \leq 342 \]  
\[ P_{KL3} \geq 320 \]  
\[ P_{KL3} \leq 350 \]  
\[ P_{KL4} \geq 320 \]  
\[ P_{KL4} \leq 339 \]  

\[(1 - A)\left((\sum_{i=1}^{4} P_{KLi}O_{KLi}) + SC\right) \geq DC \quad \forall i \]  

\[ P_{FM1} \geq 126 \]  
\[ P_{FM1} \leq 177 \]  
\[ P_{FM2} \geq 180 \]  
\[ P_{FM2} \leq 238 \]  
\[ P_{FM3} \geq 163 \]  
\[ P_{FM3} \leq 188 \]  
\[ P_{FM4} \geq 179 \]  
\[ P_{FM4} \leq 223 \]  
\[ P_{FM5} \geq 167 \]  
\[ P_{FM5} \leq 202 \]  
\[ P_{FM6} \geq 157 \]  
\[ P_{FM6} \leq 189 \]  
\[ P_{FM7} \geq 201 \]  
\[ P_{FM7} \leq 232 \]  
\[ P_{FM8} \geq 215 \]  
\[ P_{FM8} \leq 234 \]  
\[ P_{FM9} \geq 251 \]  
\[ P_{FM9} \leq 267 \]  

\[ \left(\sum_{j=1}^{9} P_{FMj}O_{FMj}\right) \geq DS \quad \forall j \]  

\[ \left(\sum_{j=1}^{9} P_{FMj}O_{FMj}\right) \leq (1 - A)\left((\sum_{i=1}^{4} P_{KLi}O_{KLi}) + SC\right) \quad \forall i, \forall j \]  

\[ P_{KLi}, P_{FMj} \geq 0 \]  

\[ P_{KLi}, P_{FMj} \text{ integer} \]  

Equation (1) is an objective function to maximize revenue, which comes from clinker export and clinker production for 1 month. Revenue from clinker exports is obtained from multiplication of kiln production rates \( P_{KLi} \) with kiln operating hours \( O_{KLi} \), selling price of exported clinker per ton \( H_{ECL} \), and proportion of clinker exported \( A \). Revenue from clinker production is obtained by multiplying proportion of clinker in each finish mill/cement mill \( P_{FMj} \) with finish mill production rate \( P_{FMj} \), finish mill operating hours \( O_{FMj} \), and cement selling price per ton \( H_S \). Proposed model in this paper has several constraints: Kiln production rates constraints, finish mill/cement mill production rate constraints, clinker amount that is not exported must be equal or greater than clinker demand per month, constraints for cement demand fulfilment, the proportion of clinker in finish mill/cement mill must be smaller or equal to clinker amount that is not exported, and non-negativity and integer constraint.
3.3. Game Strategy

Generally represents an action or action plan to play a game. Each player takes some action or action plan and then its outcome is determined [7]. \( S_i \) is the strategy of player \( i \), then \( S = (S_1, \ldots, S_i) \) is called strategy profile. The strategies chosen by player 1 and player 2 to maximize revenue can be seen in table 1.

| Table 1. Player strategy. |
|---------------------------|
| **Player 1 Strategy**     |
| S1.1 Clinker export proportion high, kiln production rate high |
| S1.2 Clinker export proportion high, kiln production rate medium |
| S1.3 Clinker export proportion high, kiln production rate low |
| S1.4 Clinker export proportion medium, kiln production rate high |
| S1.5 Clinker export proportion medium, kiln production rate medium |
| S1.6 Clinker export proportion medium, kiln production rate low |
| S1.7 Clinker export proportion low, kiln production rate high |
| S1.8 Clinker export proportion low, kiln production rate medium |
| S1.9 Clinker export proportion low, kiln production rate low |

| **Player 2 Strategy** |
|-----------------------|
| S2.1 Proportion of clinker grinded into finish mill high, finish mill production rate high |
| S2.2 Proportion of clinker grinded into finish mill high, finish mill production rate medium |
| S2.3 Proportion of clinker grinded into finish mill high, finish mill production rate low |
| S2.4 Proportion of clinker grinded into finish mill medium, finish mill production rate high |
| S2.5 Proportion of clinker grinded into finish mill medium, finish mill production rate medium |
| S2.6 Proportion of clinker grinded into finish mill medium, finish mill production rate low |
| S2.7 Proportion of clinker grinded into finish mill low, finish mill production rate high |
| S2.8 Proportion of clinker grinded into finish mill low, finish mill production rate medium |
| S2.9 Proportion of clinker grinded into finish mill low, finish mill production rate low |

Player 1 strategy is a combination of clinker export percentage with kiln production rate. In this paper the percentage of clinker exported and kiln production rate is categorized into 3: High, medium and low. Player 2 strategy is a combination of percentage of clinker grinded into finish mill with finish mill production rate. The percentage of clinker grinded into finish mill and finish mill production rate also categorized into 3: High, medium and low.

3.4. Payoff Matrix

Payoff is a numerical expression of preference order over outcomes. Each player respectively has a different payoff function [7]. Payoff function for player 1 shown as follows:

\[
\text{Max } Z = A \left( (\sum_{i=1}^{4} P_{KL_i} O_{KL_i}) + S C \right) H_{ECL} \tag{33}
\]

From the equation above it can be seen that obtained revenue comes from amount of clinker exported. Payoff function for player 2 shown as follows:

\[
\text{Max } Z = \left( \sum_{j=1}^{9} P_{TF_j} P_{FM_j} O_{FM_j} \right) H_{S} \tag{34}
\]

This payoff function calculates clinker proportion in each finish mill, so that the clinker's contribution in cement sales can be calculated. Game strategy and payoff function are used to arrange the payoff matrix shown in table 2 below:
Table 2. Payoff matrix.

| Player 2 | S2.1 | S2.2 | S2.3 | S2.4 | S2.5 | S2.6 | S2.7 | S2.8 | S2.9 |
|----------|------|------|------|------|------|------|------|------|------|
| S1.1     | Scenario 1 | Scenario 1 | Scenario 2 | Scenario 2 | Scenario 3 | Scenario 3 | Scenario 4 | Scenario 4 | Scenario 5 | Scenario 5 |
| S1.2     | Scenario 10 | Scenario 11 | Scenario 12 | Scenario 12 | Scenario 13 | Scenario 13 | Scenario 14 | Scenario 14 | Scenario 15 | Scenario 15 |
| S1.3     | Scenario 19 | Scenario 20 | Scenario 21 | Scenario 21 | Scenario 22 | Scenario 22 | Scenario 23 | Scenario 23 | Scenario 24 | Scenario 24 |
| S1.4     | Scenario 28 | Scenario 29 | Scenario 30 | Scenario 30 | Scenario 31 | Scenario 31 | Scenario 32 | Scenario 32 | Scenario 33 | Scenario 33 |
| S1.5     | Scenario 37 | Scenario 38 | Scenario 39 | Scenario 39 | Scenario 40 | Scenario 40 | Scenario 41 | Scenario 41 | Scenario 42 | Scenario 42 |
| S1.6     | Scenario 46 | Scenario 47 | Scenario 48 | Scenario 48 | Scenario 49 | Scenario 49 | Scenario 50 | Scenario 50 | Scenario 51 | Scenario 51 |
| S1.7     | Scenario 55 | Scenario 56 | Scenario 57 | Scenario 57 | Scenario 58 | Scenario 58 | Scenario 59 | Scenario 59 | Scenario 60 | Scenario 60 |
| S1.8     | Scenario 64 | Scenario 65 | Scenario 66 | Scenario 66 | Scenario 67 | Scenario 67 | Scenario 68 | Scenario 68 | Scenario 69 | Scenario 69 |
| S1.9     | Scenario 73 | Scenario 74 | Scenario 75 | Scenario 75 | Scenario 76 | Scenario 76 | Scenario 77 | Scenario 77 | Scenario 78 | Scenario 78 |

A total of 81 scenarios are found in the payoff matrix, obtained from game strategy in table 1. Scenario 1 for example, is obtained from player 1 strategy S1.1 and player 2 strategy S2.1.

4. Data Experiment

The proposed model is demonstrated through data experiment. This demonstration using real data, except for clinker export price and cement price due to confidentiality, from one particular cement industry’s production plan and monthly production report. The data shown in table 3 below:

Table 3. Data from production plan and monthly production report.

| Parameter | i or j | DS  | DC  | OKLi | OFMj | PRj | HE  | CL  |
|-----------|-------|-----|-----|------|------|-----|-----|-----|
| 1         | 950,640 | 703,474 | 100 | 200 | 0.06 | 235,186 |
| 2         | 480    | 528  | 0.92 |
| 3         | 696    | 528  | 0.65 |
| 4         | 696    | 528  | 0.88 |
| 5         | 696    | 528  | 0.65 |
| 6         | 552    | 0.88 |
| 7         | 552    | 0.65 |
| 8         | 528    | 0.65 |
| 9         | 528    | 0.65 |

Simulation in LINGO 11.0.0.20 was held based on model formulation in section 3.2 and table 3. The result of simulation can be seen below:

Table 4. Simulation result.

| Parameter | i or j | LINGO Result | Actual Data | % Error |
|-----------|-------|--------------|-------------|---------|
| 1         | 339   | 177          | 333.5       | 169.7   | 1.65   | 4.30   |
| 2         | 342   | 238          | 325.2       | 183.6   | 5.17   | 29.63  |
| 3         | 350   | 188          | 325.7       | 179.1   | 7.46   | 4.97   |
| 4         | 339   | 223          | 315.8       | 191.9   | 7.35   | 16.21  |
| 5         | 202   | 172.6        | 17.03       |
| 6         | 189   | 157.9        | 19.70       |
| 7         | 232   | 219.6        | 5.65        |
| 8         | 234   | 224.2        | 4.37        |
| 9         | 267   | 263.5        | 1.33        |

Simulation result shows that with clinker export proportion (A) 6%, kiln and finish mill production rates should be rolled out with maximum rates to get maximum revenue. These results are different from the actual monthly report data, especially in finish mill 2, 4, 5 and 6 production rate (more than 15%
error). These differences may be caused by several factors such as type of cement ground in finish mill, consideration of remaining storage space so finish mill run with a low production rate, and downtime at kiln and finish mill.

The payoff matrix is obtained based on game strategy in table 1, equation (33) & (34), and experiment data. Data used in this experiment shown in table 5 below:

**Table 5. Experiment data.**

| i or j | High | Medium | Low | 90% | 80% | 10% |
|-------|------|--------|-----|-----|-----|-----|
| 1     | 339  | 330    | 320 | 177 | 152 | 126 |
| 2     | 342  | 331    | 320 | 238 | 209 | 180 |
| 3     | 350  | 335    | 320 | 188 | 176 | 163 |
| 4     | 339  | 330    | 320 | 223 | 201 | 179 |
| 5     | 202  | 185    | 167 |     |     |     |
| 6     | 189  | 173    | 157 |     |     |     |
| 7     | 232  | 217    | 201 |     |     |     |
| 8     | 234  | 225    | 215 |     |     |     |
| 9     | 267  | 259    | 251 |     |     |     |

The payoff matrix obtained is as follows:

**Table 6. Payoff matrix (using experiment data).**

The payoff matrix in table 6 then simulated into Gambit 15.1.1 software to obtain the equilibrium. The result is shown in figure 2:

**Figure 2. Equilibria of game.**

Payoff value of equilibria 1 is 189631940, equilibria 2 is 187308019, and equilibria 3 is 200786760. Because objective function in this study is to maximize revenue from clinker production, equilibria 3 is chosen. Game strategy used to obtain equilibria 3 is S1.4 and S2.4. Referring to table 1 and table 5, S1.4 can be interpreted as: Clinker export percentage is 20% with high kiln production rate. Also, S2.4 can be interpreted as: Proportion of clinker grinded into finish mill is 80% with high finish mill production rate.

**5. Conclusion**

Clinker export is an alternative to obtain revenue in the condition of cement oversupply. In this paper a model has been proposed to determine the proportion of clinker exported and the proportion of clinker grinded into cement using the cooperative game theory approach. Simulation result in table 4 shows that kiln production rate and finish mill production rate should be set to maximum so that maximum revenue
can be obtained. Production rate resulted from simulation is different from actual data, especially in finish mill production rate.

The strategy in table 1, equation (33) & (34) and experiment data in table 5 used to compile the payoff matrix in table 6. The payoff matrix is then simulated in Gambit 15.1.1 software to determine proportion of clinker exported and proportion of clinker grinded into finish mill, which can be accepted by player 1 and player 2. Equilibria in figure 2 shows that 20% clinker export proportion and high kiln production rate combined with 80% clinker grinded into finish mill and high finish mill production rate should be accepted by both player 1 and player 2 to maximize revenue. However, this result may differ if: Different clinker export proportion value (A) is used and various categorization in formulating game strategy is applied (i.e., other than 3 categorizations of $A$, $P_{KL_i}$, and $P_{FM_j}$). Future research will consider several things as follows in order to represent actual situation at plant:

- Downtime that occurs in kiln and finish mill.
- The type of cement that is grinded in finish mill.
- Storage capacity and storage space.
- Clinker export demand.

References

[1] Chatain O. Cooperative and Non-Cooperative Game Theory. The Palgrave Encyclopedia of Strategic Management. doi.org/10.1057/9781137294678.0132

[2] Liu Z, Liu Q, Xu W, Zhou Z, Pham DT. Human-robot collaborative manufacturing using cooperative game: framework and implementation. Procedia CIRP. 2018;72:87–92. doi.org/10.1016/j.procir.2018.03.172

[3] Hafezalkotob A, Chaharbaghi S, Lakeh TM. Cooperative aggregate production planning: a game theory approach. J. Ind. Eng. Int. 2019 Feb 12;15(S1):19–37. doi.org/10.1007/s40092-019-0303-0.

[4] Winston WL. Operations Research: Applications And Algorithm, Belmont. Brooks-Cole-Thomson Learning. 2004.

[5] Emir T, Güler MG. Production Planning Using Day-Ahead Prices in a Cement Plant. Exergetic, Energetic and Environmental Dimensions. 2018;149–66. doi.org/10.1016/b978-0-12-813734-5.00009-3.

[6] Bellabdaoui A, Teghem J. A mixed-integer linear programming model for the continuous casting planning. Int. J. Prod. Econ. 2006 Dec;104(2):260–70. doi.org/10.1016/j.ijpe.2004.10.016

[7] Nishino N, Tjahjono B. Game theory approach to product service systems. Procedia CIRP. 2018;73:304–9. doi.org/10.1016/j.procir.2018.03.326