System Dynamics Modeling for Petroleum Exploitation Using the ‘Drifting Goals’ Standard Model

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Abstract. In an oil drilling area, there are two oil drilling companies that have obtained permits to drill. As time goes by, the availability of existing petroleum decreases. To anticipate natural resources the government only prioritizes one company. Competition occurs between the two of them to explore petroleum from the ground so that they can drill. The purpose of this study is to provide an overview, how to make a system dynamics model related to the problem of oil drilling as an increasingly limited natural resource, by taking the case of the relationship between drilling companies in facing business competition. The method used is system dynamics with a standard model of mutual difficulties (drifting goals). The result obtained is a system dynamics model that can be used to demonstrate the behavior of a simulated petroleum drilling model to get an overview or condition of the limitations of petroleum and future availability.

Keywords: system dynamics, modeling, drifting goals, petroleum, drilling activity

1. Introduction

Introduction is an event that involves two or more parties who jointly use limited resources and get as much benefit as possible which ends in mutual difficulties. The mutual difficulty model is based on a basic success limit structure. A group of individuals focus on self-fulfillment by using free natural resources such as water, air, animals and plants, as well as minerals contained in the earth. In every case of mutual difficulty, these natural resources are not owned by a particular group or individual. This resource is assumed to be something that is free to be owned by anyone. Every player in the system has the pattern of thinking that they can exploit natural resources without having the burden of having to pay for it. For maximum profit, the exploitation is even more intense. If the exploitation activity never reaches the limit value, then mutual difficulties will never occur. Natural resources will reach their limits if exploitation continues to increase. When humans realize that these natural resources are increasingly difficult to obtain, they will further improve technology, which will lead to increased exploitation and will further accelerate the destruction of these natural resources. In line with the decline in existing petroleum reserves, the annual oil production has also experienced a downward trend. In 2012 oil production reached 314.67 million BBL and in 2018 oil production decreased to
281.83 million BBL. The average annual decline in production is around 2%. Figure 1 is a graph of the dynamics of Indonesia's oil production in the 2012 - 2018 period.

![Indonesia's oil production for the period 2012-2018](image)

**Figure 1. Dynamics of Indonesia's oil production for the 2012-2018 period (Million BBL)**

From the example of the two companies competing with each other to exploit as much oil as possible, the more that is exploited the greater the profit that will be obtained. However, it is not realized that because petroleum is a non-renewable resource, over time this resource will be depleted. So that the more resources are taken, the profit that each company gets from its total activities will decrease. As a result, not only the two companies competed and suffered losses, but all humans also experienced difficulties.

Meanwhile, the current crude oil price in Indonesia tends to continue to decline, Figure 2.

![Crude Oil Price Condition](image)

**Figure 2. Crude Oil Price Condition**

2. Literature Review
The System Dynamics conceptualization was developed in the 1950's at the Massachusetts Institute of Technology (MIT) by Dr. Jay W. Forrester in the book Industrial Dynamics. System Dynamics is a field of study on the structure and behavior of sociotechnical systems to guide effective decision making, learning, policies in a world full of dynamic complexity [1]. According to[2] there are 4 (four) stages in building a dynamic model, namely:

1. Conceptual arrangement in the Causal Loop Diagram (CLD) model
   In drafting the concept of this model, the symptoms or processes to be imitated need to be understood first by determining the elements that play a role in the symptoms or processes into CLD.
2. Making a flow chart model or Stock and Flow Diagram (SFD)
   Following up from the previous stage, the concept of ideas that have been obtained is formulated as a model in the form of a description, image or formula, where the model in the form of an image is called a water diagram.

3. Simulation in the form of a time chart and time table
   In quantitative mode, simulation is performed by entering data into the model, where calculations are carried out to determine the behavior of symptoms or processes.

4. Validate the simulation results
   Validation is carried out to determine the suitability of the results obtained with the symptoms or processes being imitated. The model can be declared good if the error or deviation of the simulation results from the simulated symptoms or processes is small (below 10%).

Meanwhile, are several stages in modeling using System Dynamics [3], namely:
   a. Problem identification and definition
   b. System conceptualization
   c. Model formulation
   d. Model behavior analysis
   e. Testing and Model Development
   f. Policy analysis

Furthermore, in chart form, the steps above can be represented in Figure 3.

![Figure 3. Cycle Model of System Dynamics](image-url)

3. Methodology
Causal Loop Diagrams are expressions of causal relationships in a particular image. One of the elements of cause and effect refers to a measured condition qualitatively (perceived) or quantitatively (actual). Process (rate) or information about a state as a cause that produces a state (level) or influence on a process as a result or vice versa as illustrated below [4].

Causal Loop Diagram is a tool to simplify system structuring. Each system has different dynamic behavior patterns that can be used as initial guidelines in building a more detailed dynamic structure or for analysis [5], then it can only be identified the types of effects caused by causes, namely direction-effect, and it can be seen the type of effect caused by the cause, namely the same direction or the opposite direction. If the relationship is unidirectional, then the arrow is positive (+); if the direction is opposite, the arrow is negative (-) [6].

The next process is to assemble a causal relationship to produce loops. The positive or negative properties of loops are known by looking at the results of the entire arrow interaction process in a loop; unidirectional (called positive loop) or opposite direction (called negative loop). Positive loops
behave as acceleration or deceleration. The negative loop behaves towards the target above the limit. There are two types of goals, namely goals towards explicit: greater than 0 and targets towards implicit: close to 0 [7].

The author uses the Causal Loops Combination of positive (+ / reinforcing) and negative (- / balancing) loops as illustrated in Figure 4.

Figure 4. Causal Loop Diagram

For the cases in the two drilling companies, data is given as in Table 1.

Table 1: Function of petroleum exploitation time

| Time | drilling A | drilling B |
|------|------------|------------|
| 1    | 4.80       | 2.40       |
| 2    | 5.76       | 2.88       |
| 3    | 6.91       | 3.46       |
| 4    | 8.32       | 4.16       |
| 5    | 10.08      | 5.04       |
| 6    | 12.32      | 6.16       |
| 7    | 15.22      | 7.61       |
| 8    | 19.00      | 9.50       |
| 9    | 23.90      | 11.95      |
| 10   | 30.18      | 15.09      |
| 11   | 38.02      | 19.01      |
| 12   | 47.45      | 23.72      |
| 13   | 58.26      | 29.13      |
| 14   | 70.05      | 35.02      |
| 15   | 82.25      | 41.12      |
| 16   | 94.29      | 47.15      |
| 17   | 105.72     | 52.86      |
| 18   | 116.23     | 58.12      |
| 19   | 125.73     | 62.86      |
| 20   | 134.21     | 67.11      |
| 21   | 141.76     | 70.88      |
| 22   | 148.50     | 74.25      |
| 23   | 154.55     | 77.28      |
| 24   | 160.02     | 80.01      |
| 25   | 165.02     | 82.51      |
| 26   | 169.63     | 84.81      |
| 27   | 173.91     | 86.96      |
| 28   | 177.93     | 88.97      |
| 29   | 181.74     | 90.87      |
| 30   | 185.36     | 92.68      |
The next process is to develop a Casual Loop Diagram that has been formed into a Stock Flow Diagram that can be simulated to try to see changes in the values of the variables used in this study as shown in Figure 5.

To get the results from simulation, the author used several mathematical equations to find the changes in each variable. Some of the equation are listed below:

The POWERSIM Equation is:

- \( \text{init} \) drilling_A = 4
- \( \text{flow} \) drilling_A = \( +dt \times \text{Total_Profit}_A \)
- \( \text{doc} \) drilling_A = Activities undertaken by Company A to obtain petroleum
- \( \text{init} \) drilling_B = 2
- \( \text{flow} \) drilling_B = \( +dt \times \text{Total_Profit}_B \)
- \( \text{doc} \) drilling_B = Activities undertaken by Company B to obtain petroleum

\[ \text{Total_Profit}_A = \text{drilling}_A \times \text{profit_per_drilling} \times \text{profit_fuction}_A \]

\[ \text{Total_Profit}_B = \text{drilling}_B \times \text{profit_per_drilling} \times \text{Profit_Function}_B \]

\[ \text{profit_per_drilling} = \frac{\text{limited_resources}}{\text{DELAYMTR(\text{total_activity},10,3,18)}} \]

\[ \text{total_activity} = \text{drilling}_A + \text{drilling}_B \]

\[ \text{limited_resources} = 120 \]

\[ \text{profit_fuction}_A = 0.03 \]

\[ \text{profit_fuction}_A = \text{Profit Constant A}. \]

\[ \text{profit_fuction}_B = 0.03 \]

\[ \text{Profit_Function}_B = \text{Profit Constant B}. \]

In graphical form it can be seen the output of the data simulation results as shown in Figure 6.
The initial performance conditions of the two drilling companies in relation to Petroleum resources and their estimated future conditions are presented in the forecast as shown in Figure 7.

**Figure 6: Comparison of Drilling A and Drilling B**

**Figure 7: Comparison of Total Profit A and Total Profit B**

**Dimensional analysis**

The total profit A is the multiplication of drilling A multiplied by the profit per drilling and multiplied by the profit fraction A. While the profit fraction is the profit constant A expressed by the fraction/barrel [8].

**4. Results and Discussion.**

The graph of the relationship between drilling A and drilling B and the benefits of drilling with time is presented in Figure 8.
Next, the relationship between the conditions of the drilling company Company A and company B in relation to the total profit, is presented in Figure 9 and Figure 10.

In the form of a function of time between the conditions of the drilling company A and company B in relation to the total profit, is presented in Table 2.
Table 2. The relation between drilling A and drilling B and its profit

| Time | drilling_A | drilling_B | profit_per_drilling |
|------|------------|------------|---------------------|
| 0    | 4.00       | 2.00       | 6.67                |
| 1    | 4.80       | 2.40       | 6.67                |
| 2    | 5.76       | 2.88       | 6.67                |
| 3    | 6.91       | 3.46       | 6.79                |
| 4    | 8.32       | 4.16       | 7.05                |
| 5    | 10.08      | 5.04       | 7.42                |
| 6    | 12.32      | 6.16       | 7.85                |
| 7    | 15.22      | 7.61       | 8.27                |
| 8    | 19.00      | 9.50       | 8.61                |
| 9    | 23.90      | 11.95      | 8.76                |
| 10   | 30.18      | 15.09      | 8.66                |
| 11   | 38.02      | 19.01      | 8.28                |
| 12   | 47.45      | 23.72      | 7.60                |
| 13   | 58.26      | 29.13      | 6.74                |
| 14   | 70.85      | 35.02      | 5.81                |
| 15   | 82.25      | 41.12      | 4.88                |
| 16   | 94.29      | 47.15      | 4.04                |
| 17   | 105.72     | 52.86      | 3.32                |
| 18   | 116.23     | 58.12      | 2.72                |
| 19   | 125.73     | 62.86      | 2.25                |
| 20   | 134.21     | 67.11      | 1.88                |
| 21   | 141.76     | 70.88      | 1.58                |
| 22   | 148.50     | 74.25      | 1.36                |
| 23   | 154.55     | 77.28      | 1.18                |
| 24   | 160.02     | 80.01      | 1.04                |
| 25   | 165.02     | 82.51      | 0.93                |
| 26   | 169.63     | 84.81      | 0.842               |
| 27   | 173.91     | 86.96      | 0.771               |
| 28   | 177.93     | 88.97      | 0.712               |
| 29   | 181.74     | 90.87      | 0.665               |
| 30   | 185.36     | 92.68      | 0.625               |

Based on the simulation results, it can be seen that drilling company A and drilling company B show tight competence in petroleum drilling. This can be seen in the time graph and time table, where drilling company A and drilling company B from time to time show a sharp increase in drilling activities so that petroleum resources experience a decline which in the end is threatened with exhaustion. In this case, the government and stakeholders are trying to anticipate these natural resources [9].

The results of oil drilling at company A and company B are limited by limited natural petroleum resources. This has an impact on the depletion of irreplaceable natural petroleum resources.

In the common difficulty model, individuals exploit public property resources with actions that are solely aimed at their own benefit without paying attention to the collective impact caused by the actions of each individual. After some time, the exploitation carried out has exceeded the carrying capacity of existing resources and resulted in a decrease in the benefits obtained. as a result of this overexploitation, the available resources will eventually run out [10].

Like the success limit model, the shared difficulties model can help us to deepen the implications of finite sources, and like the 'Success for the Success' model. This complex structure can describe the complexity of using resources simultaneously. The shared difficulties help us to consider ways to monitor the use and limitations of natural resources and use them to regulate their use. Figure 11.

This structure can help us to recognize the consequences of development and technological developments. This structure underlines the use of natural resources and the impact of development and growth on the sustainability of these natural resources [11].
5. Conclusions
The system dynamics model can be used to demonstrate the behavior of a petroleum drilling simulation model to get an overview or condition of the limitations of petroleum and its availability in the future according to the following points:

1. The common difficulty model can be identified from the existence of limited resources with absolute prices, which from the behavior graph shows its behavioral phases, namely the slow growth phase, the slow decline phase, and the fast decline phase.
2. The system dynamics model can be made from several large loops such as population growth with population, oil energy consumption with oil stocks, oil energy production with oil reserves and oil reserves with additional renewable reserves.
3. The dynamics of Indonesia's oil reserves have decreased every year. This decrease causes the production rate to decline further, along with this decline, domestic consumption needs to continue to increase. To meet domestic needs, the government imports to other countries by taking into account the slow decline phase and the fast decline phase.

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