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SIMULATION–OPTIMIZATION TRUCK DISPATCH PROBLEM USING LOOK – AHEAD ALGORITHM IN OPEN PIT MINES

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ABSTRACT: Material transportation in open-pit mines area contributes to 50% of the operating costs. Therefore, efficiency on the material transportation, specifically in truck dispatching problem needs to be done in order to get the best dispatching rules for the allocation of trucks and loaders. This research uses look-ahead algorithm approach as a new method to solve truck dispatch problem in open-pit mines area. The proposed approach was developed by simulation and optimization model in solving the truck dispatch problem using real data-situation. The dispatching result aims to answer the question where and when should a truck go so that could maximize the number of production and provide significant operating cost savings to the mining industry. This study uses a discrete event simulation to test several scenarios methods of truck dispatch, including LP-Gap, the percentage of LP-Gap, multi-stage algorithm and look-ahead algorithm. The results of the research shows that the look-ahead algorithm scenario gives the highest result with the number of production, productivity of loaders, productivity of trucks with block and without block; 43,533 ton, 64.44%, 80.53% and 63.47%.

Keywords: Discrete Event Simulation, Look-Ahead Algorithm, Simulation and Optimization, Truck Dispatch Problem

1. INTRODUCTION

Indonesia became one of the richest countries in energy and mineral resources. With an area of 1,910,931 km^2, Indonesia has abundant resources such as petroleum, natural gas, nickel, coal and others. Based on Mineral Resources and Energy Ministry [1] in 2011 the availability of coal resources Indonesia reached 120,338 million tons and reserves of 28,017 million tons. This amount is spread in several parts of Indonesia, both South Sumatra and East Kalimantan was the two regions that have the resources and the largest coal reserves compared to other areas. In addition, Indonesia also has one of the largest coal producers in the world as much as 281.7 million tons have been successfully produced in 2014 as the third world rankings after China (1844.6 million tons) and the United States (507.8 million tons) [2].

As one of the highest coal producing countries, Indonesia has a reliance on the use of coal as a power plant, it can be seen from the General Plan of Power-Owned National Electricity Company in 2013-2022 states that the total capacity of power plants in Indonesia reached 47 GW in 2015 with 25 GW of which are coal-fired power plants. Proven by a report from Indonesia Energy Outlook [3] there was a significant increase to the growth of new coal-fired plants of 2014 amounted to 0.76 thousand MW by 2016 of 1.86 thousand MW and forecast to 2020 by 7.16 thousand MW.

Moreover, the energy mix of coal has increased the portion of the year 2013 by 24% to 2025 by 31% [3]. It shows that the coal in Indonesia has a very important role for national energy security, as a revenue generator for the Indonesian economy. However, since the year 2011 to 2016 there has been decreasing of the coal price index by 63.4% from the highest price in 2011 (139.05 USD) [4]. Decreasing of coal prices led to the coal company declining in profits. Therefore, it needs to improve efficiency in order to make profit.

One of the efficiencies that can be done through efficiency on the operational side. As mentioned by Alarie & Gamache [5] and Ercelebi & Bascetin [6] the material transportation represents 50 per cent of the operating costs for an open pit mine. Therefore, one of the efficiencies that can be done and has a substantial impact through efficient on truck dispatching problem in the mine area. Zhang and Xia [7] stated that truck dispatch system, where the transport of material from the mine site to the dump area for further processing, plays an essential role on the issue of open-pit mining.

Therefore, one of the steps of efficiency for the company to survive by increasing operational performance on truck dispatch problems in coal mine area through optimization and simulation approach.

2. METHODS

Truck dispatch problem occur in some circumstances practical in the real world, both in the mining industry or any industry outside of it, especially in industries that require their settings fleet use, as quoted from Subtil, Silva, and Alves [8] as an example of the shipping industry and delivery of goods [5], oil and gas product delivery [9], transportation of raw materials [10] and etc.

Transportation and material movements by truck and loader particularly in coal represent 50-60% of operating costs in the mining industry [6]-[7].

Based on Alarie and Gamache [5] said that the truck dispatch problem in mining industry is trying to answer the question of "Where should this truck when it go and leave this place?" Therefore, become important thing to decide where the best destination to send a truck and when, in order to meet the requirements of production targets and minimize operating costs.

In addition, a lot of the mining industry still applies one strategy assignment truck called Fixed Truck Assignment (FTA) approach as a best practice to Truck Dispatching Policy in the area of mining operations [7],[11]. FTA approach is truck assigned to a fix route between the loaders and dump point during operational shift work [12]. FTA caused very long queues in the area of loaders for their randomness of equipment breakdown and the stochastic nature of the haulage process [12].

In answer to these challenges, there was a research done by He, Wei, Lu, & Huang [13] with optimization of the number of trucks in the mine area by using Genetic Algorithm. Different to other researcher, Subtil, Silva & Alves [8] discussed about maximize the amount of mine production by using Multistage Algorithm (Allocation Planning & Dynamic Allocation). Another issue Zhang and Xia [7] have already done by minimize operating costs truck using Integer Programming - Lower Stage (Truck Assignment for Shovel).

Completion by using the above methods have been carried out and the impact is quite effective to the objectives to be achieved. However, solving the above problem has not been able to predict the future of the optimal routes for truck toward loader in real-time and optimal to meet production target. Therefore, look-ahead algorithm method becomes one of method which could apply to the truck dispatch problem in open pit mine area. This method has been widely used for utilization of container relocation problem by Jin, Zhu, & Lim [14] and Zhu & Lim [15]. Look-ahead method aims to take into account and react to changes in real-time systems [16]. Hence through this method two to five trucks behind the queue before it reaches the point for dispatching, the trucks have to know in advance the loader point which will be addressed based on the needs of each shovel to transport and based on a production target that has been set.

Look-ahead procedure is an approach used in solving the problems to dispatch the truck to look ahead what will happen near future in a system based on previous information gathered, as a reference to decide the scheduling for entities that exist in back of the queue [17]. A look-ahead can save a lot of information about the system status, such as information about what is scheduled in the near future with great accuracy, which can be used to control manufacturing operations.

Look-ahead could predict two or more of the truck's destination. In general, it can be narrowed down to two steps as can be seen in Fig. 1, i.e. Look-ahead procedure and level of evaluation function [14].

Look ahead dispatching procedure apply limited tree search in giving alternatives or suggestions in order to make the combination of assignment to an entity that will be assigned. The size of the look-ahead tree would increase exponentially as the search depth increases, so it is impossible to explore the whole search space [14]. To overcome this drawback, we impose limitation both on the depth of the tree search and on the number of children generated for each branch node. So there are only a limited few combinations to be inspected on the look-ahead tree, to be able to build a search tree consisting of branches that are very promising in the hope of leading to a high-quality solution [14].

Evaluation function in the look-ahead algorithm has to evaluate the function of each node resulting from the previous procedure on the look-ahead tree. Possible future system conditions further assessed based on the stages of evaluation function [17]. So at this stage of the evaluation function, as can be seen in Fig. 1 has a function as a determinant of decision rules in determining the combinations of existing nodes in accordance with the desired or expected criteria of the modeler.

In addition, this study will compare the results of the use of multi-stage method to methods that have been developed by a company called LP-Gap method and the percentage of LP-Gap. LP-Gap method is the development of a model to optimize the dispatch of the truck to loader based on the difference of the truck needs (LP-Truck) in each shovel compared to the number of trucks being and heading to shovel point. The percentage of LP-Gap method is to calculate the percentage of LP-Gap at each loader by dividing the number of LP-Gap at each loader with number of LP-Truck in each loader.

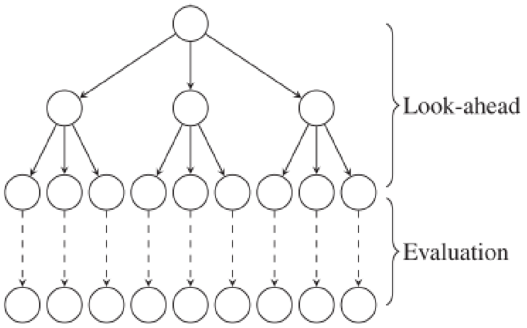

Fig. 1 Look-Ahead algorithm structure

The objective of this study aims to obtain best assignment rules for the allocation of the truck and loader used in the mining industry through the optimization and simulations are conducted to increase production targets and reduce operating costs.

3. MODEL CONSTRUCTION

In the logistic business, trucks are important vehicle type used for transporting of goods [18]. Defining the speed limits based on the concept of optimal speed of road transport systems has a significant part in the speed management of vehicles [18]. Based on research which has been conducted by Outapa, Kondho & Thepanondh [18] stated that speed of truck which gave the best optimal result in terms of logistic business was 40 km/hr. But the behavior of a system built on the model in accordance with the real situation where the speeds of truck vary widely due to the standard deviation of the traveling time is very high in each of the routes.

First step of model construction is gathering data and collecting data. The data area mentioned as follows i.e. truck cycle time, travelling time truck, hauling time truck, the quantity of load, loader maneuver time, loader loading time and loader spotting time.

Referring to the behavior of a system that has been described, this research conducts a conceptual model that describes the characteristics of the model building process. The conceptual model consists of input, process and output in running models. The output variables generated are the number of production, loader productivity, truck productivity with blocks and truck productivity without block. The input variables used are the number of trucks used, the amount of the existing loader, truck cycle times, and service time loader. The objective of this model is to get the best dispatch rules for the allocation of truck and loader to be able to increase the amount of production. This model consists of one dumping point, one intersection point and three point loader which has 3 different routes. In the conceptual model, there are four methods of scenario as a strategy to solve the problems in the area of the mine truck assignment among which LP-Gap, Percentage LP-Gap, Multi-Stage Algorithm, and Look-Ahead Algorithm.

3.1 LP-Gap Method

In the scenario method LP-Gap see Eq. (1) – (2), in the early stages will be calculated on the LP-Truck or the truck needs at each loader by using a comparison between the cycle time in each the truck loader divided by spotting and loading time of each loader. LP-Gap itself is the result of the calculation of the difference between the number of trucks on the needs of each loader with the number of trucks that were to and heading in each loader. This method can be calculated both in dumping point and intersection point. It was called Reassignment Calling Point (RCP). This method would dispatch the truck loader which has the biggest LP-Gap.

$$\text{LP-Truck} = \frac{\textbf{Cycle Time Truck i}}{\textbf{Spotting and Loading Time Loader i}} \quad (1)$$

i = Route option

$$\text{LP-Gap} = \alpha - \beta \quad (2)$$

α = Amount of LP-Truck i

β = Trucks heading to and being in the loader i

3.2 Percentage of LP-Gap Method

In the scenario method percentage LP-Gap see Eq. (3), generally have the same stage with LP-Gap method. In the next stage is to calculate the percentage of LP-Gap in respective loader by dividing the number of LP-Gap at each loader with the number of LP-Trucks in each loader. This method has been used; due to a loader could be less utilization. Then, it was done because there are others loader who have a greater LP-Gap. This method can be calculated both in dumping point and in intersection point. It was called Reassignment Calling Point (RCP). This method would dispatch the truck loader which has the largest percentage of LP Gap.

$$\text{Percentage of LP-Gap} = \frac{\textbf{LP-Gap i}}{\textbf{Amount of LP-Truk i}} \quad (3)$$

i = Route option

3.3 Multi-Stage Algorithm

In the scenario method Multi-Stage algorithm based on Subtil, Silva, & Alves [8] there were two stages to be conducted. In the initial phase, find a maximum production capacity of the mine area and determine the optimal number of the truck required to achieve production targets. In the second phase, dynamic allocation, the allocation algorithm is looking for the best schedule to request assignment to comply with the allocation plan, using heuristic dynamic delivery using multi-criteria and discrete simulation.

Stage 1 is called with the allocation planning. Allocation planning is to determine the needs of each truck loader by calculating hourly load rate shovel, see Eq. (4).

$$\text{HLRS} = \frac{\mathbf{3600}}{\textbf{Spotting and Loading Time Loader i}} \quad (4)$$

HLRS = Hourly load rate shovel
i = Route option

Next, calculate the difference between the requirement hourly load rate shovel with the number of trucks that have been dispatched to each loader. Loader which has the biggest difference will be assigned to its loader's route. Moreover, there are two other constraints are considered to determine the decision in dispatching a truck on this method, i.e. considering the loader idle status and the number of queues at each loader.

In this method will be recalculated at the point of intersection. Therefore by doing these calculations could be information which has been received from the system will be much more accurate. It can increase productivity in the field. Stage 2 is dynamic allocation. This phase runs every time the truck asking for allocation i.e. when one finishes dumping, when a truck starts to work, and when the loader has been idle. It aims to find an allocation for the trucks that best meets the allocation planning, i.e., finds the allocation to meet the following goals are: to improve truck productivity, to minimize queuing time at the loader, and to minimize the loader idle time; all of these goals are treated considering all the operational constraints at the mine [8].

3.4 Look-Ahead Algorithm

Look-Ahead algorithm implement tree search limited in providing an alternative to create a combination order of assignment to an entity that will be assigned. In this study is limited to 5 trucks backward will be calculated. This study has three route options, the combination of route options that will be generated as many as 243 combinations of routes option.

After created 243 a combination of route options, the next step is determining the choice of the route to be selected based on the criteria of evaluation function. Evaluation function in the look-ahead algorithm tasked to evaluate each node resulting from the previous procedure on the look-ahead tree. Furthermore, the possibility of future conditions in the system assessed based on the stage of evaluation function.

The evaluation function used in this study is taking into account productivity each loader and loader queue. The formula of productivity loader calculation could be seen in the Eq. (5).

$$\text{Loader Productivity} = \frac{\textbf{Prediction total production i}}{\textbf{PLW i} - \textbf{current time}} \quad (5)$$

PLW = Prediction duration trucks and shovel work
i = Combination route option

Look Ahead method also considers the number of queues resulting from each of route option combination. The combination of route option previously is generated on the limited tree search that has been built on the model algorithm. Therefore the route option obtained is a combination of routes options which have high loader productivity and minimize the number of queues. Through this method, the algorithm will be tested at the dumping point and also at the intersection point.

This algorithm tries to predict what will happen next and keep updating for real time condition. Therefore, the information on this system will be constantly updated to make it more accurate and able to predict events that will happen next.

4. RESULT AND DISCUSSION

The model was being verified by debugging on the simulation model and examining the conformity of the model with the model formulation to show that the model is appropriate to the model conceptualization and ensure that it works correctly. Then the model was also being validated by comparing the model configuration to the factual data. The configurations which are compared are amount of coal production, loader productivity, truck productivity with block and without block. All methods used have been developed using discrete event simulation by using software ProModel 7.5. Simulations have been run for 11 hours / 660 minutes / 39600 seconds with a precision clocked 0.001 seconds and replicated 30 times.

Figure 2 shows boxplot chart of the overall scenario methods that have been done on the simulation and optimization models. It is calculated based on the amount of daily production with replicated 30 times. Through the boxplot, it can be conclude that look-ahead algorithm method is able to give the best results compared to other scenarios method. It can be seen from the median production quantities are in the range of 43,000 to 44,000. While the amount of production in other scenarios method (LP-Gap and Percentage LP-Gap) lie in the range of 38,000 to 42,000. In addition, from the boxplot could be seen that each algorithm which is done recalculation at the intersection point (RCP) or the calculation only at the intersection point showed better results than the calculation which is done at the dumping point only. The condition is caused due to the information obtained by the algorithm in real time condition will be more accurate if the calculation at the intersection point.

Table 1 shows the results of output indicators of the whole scenario methods that have been done. From the table, it can be seen that scenarios look-ahead algorithm method is better than other methods. This can be demonstrated on the average loader productivity produced by 64.44%. The condition is caused due to look-ahead algorithm try to resolve the truck dispatch problem by looking forward (look-ahead) what will happen on near future. It is done based on the information previously collected as a reference to decide the scheduling for entities that are behind the queue. Look-ahead algorithm is also able to predict every five trucks to carry out the assignment to the loader in need.

Moreover, Look-ahead algorithm not only focuses on productivity loader as the evaluation function of the basis for decision making but also focuses on the number of queues generated on each loader. Both look-ahead algorithm and multi-stage algorithm has been simulated to eliminate the aspect of 'myopic' or short sited decision making as defined by the Alarie and Gamache [5], where the dispatch of the current truck strongly considers its effect on the next requests.

Percentage of Productivity is generated in scenario methods which do the calculations at the intersection point have a greater value than the scenario method performed calculations on the dumping point only. It can be conclude that if the calculation carried out on the intersection point will give the greater and more accurate result.

5. CONCLUSION

This research proposes the use of look-ahead algorithm method as the new method to obtain best assignment rules for the allocation of the truck and loader used in the mining industry through the optimization and simulations.

Based on the analysis from simulation-optimization models truck dispatch problems in the open pit area mining, it can be concluded that look-ahead algorithm provides the best result compared to the other scenarios method. It showed that coal production generated at 43,532.50 tons per day with productivity of loader on average by 64.44% and the productivity of the truck without a block by 80.53% and with the block by 63.47%

Multi-stage algorithm also showed better results than the method LP-Gap and percentage LP-Gap, because the method is not only based on the needs of truck in each loader every hour but also strongly considers status of utilization loader (idle or no idle status) and also consider to the number of queues in each loader.

Each algorithm method of scenario calculations performed recalculation at the intersection point or the calculation only at the intersection point showed better results than the calculation is only done at the dumping point.

On top of these results, the use of the look-ahead algorithm for truck dispatch problem has shed new light on the solving the material transportation specifically on truck dispatch problem in open pit mine. The model was able to generate the best output indicators result that presents the improvement of production targets and reduce operating costs.

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Table 1 Simulation results all scenario method of truck dispatch problem

Indicator	Scenario Method						
	LP-Gap RCP	% LP - Gap RCP	LP-Gap	% LP-Gap	Multi-Stage Algorithm	Look-Ahead Algorithm Dumping	Look-Ahead Algorithm Intersection
Coal Production	39,587	41,519	37,847	39,565	42,968	42,879	43,533
Loader 1	11,139	13,091	9,642	12,775	15,786	16,164	16,537
Loader 2	11,215	12,408	9,642	11,519	14,471	14,668	15,057
Loader 3	17,928	16,708	18,677	15,772	13,306	12,703	12,606

Table 1 Simulation results all scenario method of truck dispatch problem (cont'd)

Indicator	Scenario Method						
	LP-Gap RCP	% LP - Gap RCP	LP-Gap	% LP-Gap	Multi-Stage Algorithm	Look-Ahead Algorithm Dumping	Look-Ahead Algorithm Intersection
Loader Productivity	55.93%	58.98%	49.26%	53.14%	63.90%	63.21%	64.44%
Loader 1	59.36%	66.93%	48.93%	59.91%	79.68%	80.38%	82.85%
Loader 2	59.90%	65.37%	48.27%	54.31%	74.24%	74.19%	75.21%
Loader 3	48.52%	44.64%	50.59%	45.20%	37.77%	35.07%	35.25%
DT Productivity without block	84.28%	84.36%	82.97%	83.73%	81.26%	81.23%	80.53%
DT Productivity with block	61.44%	62.89%	58.27%	60.03%	63.59%	63.39%	63.47%

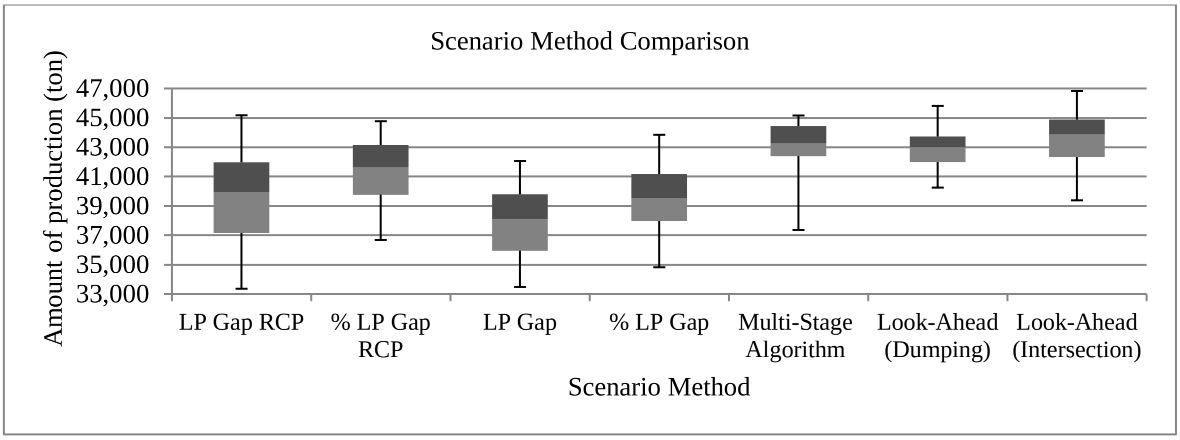

Fig. 2 Boxplot chart comparison to the scenario method

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