Multi-Criteria Evaluation and Least Cost Path Analysis for Optimal Haulage Routing in Open-Pit Mines

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1. Introduction

The operation tasks in open-pit mines consist of drilling, blasting, loading, haulage and general services. Among them, the haulage is the most expensive operation that occupies more than 50 % of the total operation cost in open-pit mines. Therefore, minimizing the haulage cost can be one of the most critical constraints for ore production.

The shovel-truck haulage system is common in open-pit mines due to the advantage that easily changes the haulage routes according to the managerial conditions (Hays 1990). The haulage cost of shovel-truck system is dependent on the productivity of an operating truck which can be represented by the average truck cycle time as follows:

$$LCT = STL + LT + TL + STD + DT + TE + AD \quad (1)$$

where LCT is the truck cycle time, STL is the spot time at loading, LT it the loading time, TL is the travel time moving to uphill, STD is the spot time at dump (turn), DT is the dumping time, TE is the travel time moving to downhill (empty) and AD is the average delay time including both waits and delays.

There were some challenges to develop an optimal truck dispatching system to optimise the productivity of an operating truck by reducing the AD (Temeng 1997; Alarie and Gamache 2002). However, relatively little attention has been addressed to the TL and TE which can be determined by the truck efficiency and especially the haulage route. Most previous studies have been assumed that the haulage route between loading and dumping area is unique. Although this assumption can be reasonable in small size open-pit mines, there can be many alternative routes between loading and dumping area in large size open-pit mines. Moreover, the favourable route of dump trucks can be differently determined or can be changed according to operational requirements and fast change of landform.

The purpose of this study is to propose a new methodology to determine the optimal haulage routes of dump truck in large size open-pit mines using multi-criteria evaluation and least cost path analysis.

2. Model development

The model for geo-processing in the conventional GIS software was developed in this study to identify the optimal haulage route of dump trucks from several thematic maps of open-pit mine. The goal of developed model was to minimize adverse costs of truck travel related to following criteria:

- Maximize average moving velocity of dump truck during haulage operations
- Minimize proximity to water-body
- Minimize proximity to coal seam
- Maximize availability of supporting equipments such as motor graders, dozers and water sprinkler trucks for pit maintenance
- Avoid steep-grade areas which unfavorable grade resistance is too strong for truck to go toward uphill or which favorable grade is beyond the truck retarding capability
- Avoid areas of water-body such as streams, natural ponds, and artificial setting ponds

Fig. 1 shows the developed model in this study. The model consists of three data processing steps: (1) rating by fuzzy membership function to identify overall discrete friction cost (within the range of 0 and 1) of each criterion; (2) weighing the each criterion using Saaty's pairwise comparisons to summarize the all costs from various criteria; (3) generating the accumulated friction cost map which represents the minimum cost from specific locations to every cells in raster-based map. The optimal haulage route can be automatically determined from the accumulated friction cost map if the starting location (loading areas in open-pit mine) is selected by mining engineers.

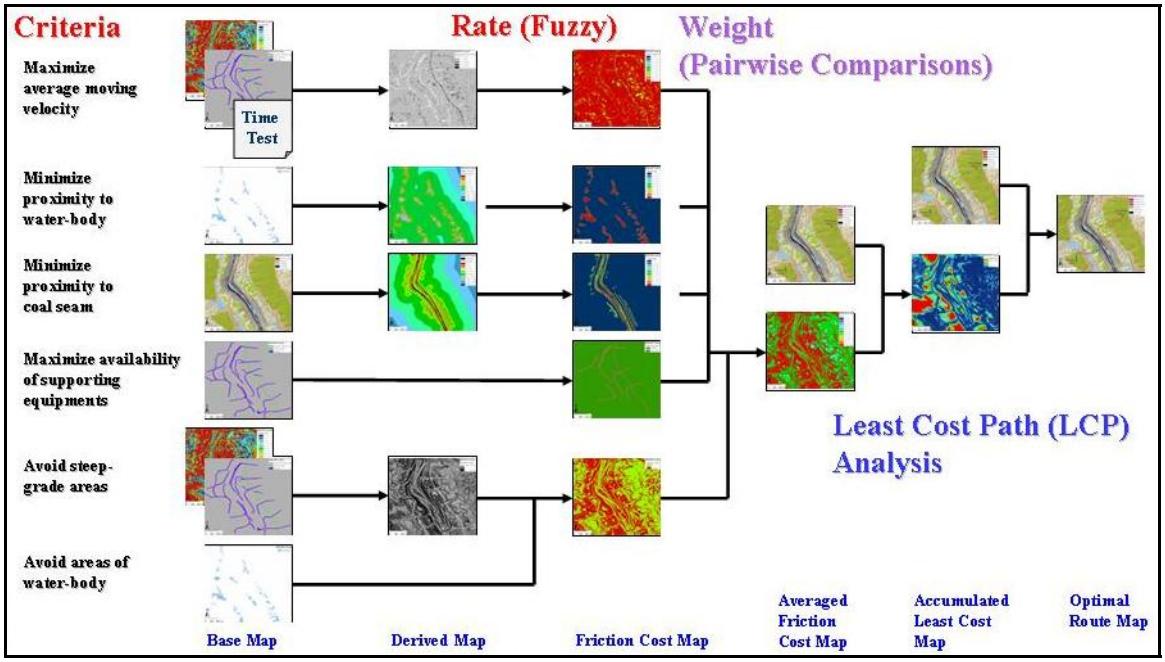

Figure 1. the geo-processing model for optimal haulage routing.

3. Application

The developed model was applied to the Pasir open-pit coal mine in Indonesia to identify the optimal route of dump trucks (100 ton) for mine waste haulage. The test area was 4.2 km × 4.2 km and closed system which means that the mine waste should be dumped in the test area, not the outside. The DEM which has 5m grid spacing was used to generate the grade of terrains and several thematic maps such as water-bodies, coal seams, haul road networks, etc. were digitised from the mine area map for geo-processing. Fig. 2 shows the optimal haulage routes derived from the developed model through the three steps of geo-processing. Because the weight of each criterion which was determined by pairwise comparisons was different between moving to uphill and moving to downhill, the optimal routes of dump trucks were also identified differently according to the moving direction.

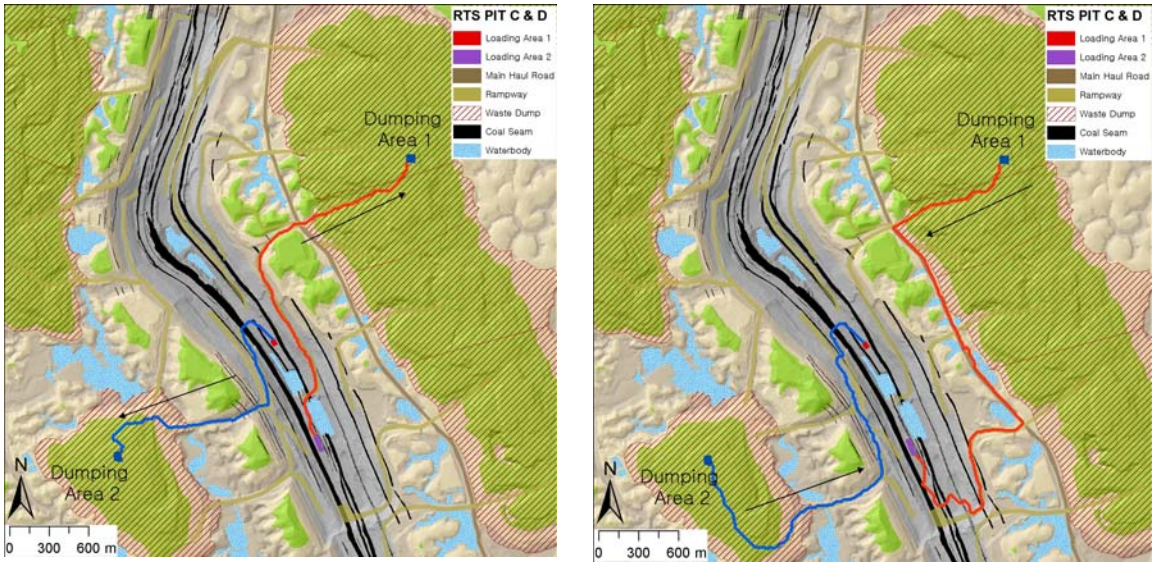

Figure 2. Optimal haulage routes of dump trucks. Moving to uphill (left). Moving to downhill (right).

4. Conclusion

In this study, a novel methodology that combines least cost path analysis and multi-criteria evaluation was proposed to determine the optimal haulage route of dump truck in open-pit mines. The model logic for optimal haulage routing considers 6 criteria which can significantly influence the planning of travel route of dump truck. Using a fuzzy membership function, the normalized friction cost that represent adverse affects of truck movement can be assigned and the weight of each criterion can be determined through the Saaty's pair-wise comparisons. The application at the ROTO SOUTH in the Pasir open-pit coal mine, Indonesia showed that the proposed methodology could make rational solutions to determine the haulage route of dump truck at the different scenarios.

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