DECISION SUPPORT SYSTEM FOR OPTIMAL SELECTION OF HAUL ROUTES BASED ON TIME SLOTS IN EARTHMOVING OPERATION

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ABSTRACT: Haul routes for earthmoving operation need to be carefully selected because the decision on the haul routes could make a significant difference in the project's cost and time. This paper proposes a decision support system for improving productivity of earthmoving operation that helps construction managers choose the best haul routes of trucks based on time slots. Also, a methodology for optimal selection of haul routes considering traffic conditions and topographic conditions of the routes is explained. Raster data model is used to find an available shortest path based on cost weighted distance. A system was developed on a geographic information system environment for efficient database management and easy manipulation of graphical data. A real-world case study was conducted to verify the applicability of the proposed system.

Keywords: Earthmoving operation; Time/Space scheduling; Travel speed; Haul route analysis

1. INTRODUCTION

In the case of earthworks in urban areas, many factors such as traffic congestion and truck restriction areas largely affect the haul speed eventually productivity of earthworks. Especially, traffic congestion during commuting time decreases haul efficiency and causes schedule delay. Also, there are often troublesome problems with truck restriction areas because truck drivers are not really aware of restriction areas. There have been researches to examine factors influencing haul speed. Smith [9] and Marzouk and Moselhi [5] quantitatively analyzed the amount of effect of factors on haul speed using regression analysis and fuzzy clustering. Christian and Xie [2] tried to find out factors on haul speed by surveying and expert interviews. Park etc. [6] derived a formula for estimating dump truck's travel speed based on regression analysis of factors such as signalized intersection density, haul distance, traffic volume per lane. Peurifoy and Schexanayder [7] described haul speed as graphs according to earthmoving operators used in actual sites, road conditions, and grade based on experimental speed data.

Construction planners need to consider many factors affecting haul efficiency when planning on haul routes. For example, the planners should take traffic volume into account because dump trucks cannot haul earth efficiently on the roads with large volume. In addition, the planners may take another route due to truck restriction areas even though it takes more time. For this reason, the planners should be well aware of traffic conditions and geographic situation.

Geographic Information Systems (GIS) were employed for effective manipulation of spatial information and the associated attributes, since many factors affecting haul speed are related to geographic information and easily expressed in a GIS environment. Using a similar approach, Seo and Kang [8] developed a GIS-based system that analyzes haul routes in rural area by considering grade resistance and rolling resistance. Yu etc. [10] considered weights of factors for minimum cost route selection in expanding roads and proposed methods for optimal route selection using GIS. Choi and Sunwoo [1] conducted analysis of optimal haul routes for dump trucks in large open pit mines, and they developed analysis model by considering factors such as grade, ground resistance and easiness of maintenance. Also, ESRI Inc. [3] developed a method for searching alternative route using raster data model. One interesting study (Kim and Park [4]) has also attempted to analyze available vehicle's travel speed using simulation model based on the number of vehicles on the road and average distance between vehicles.

This paper proposes decision support system for haul route selection to improve the productivity of earthworks by integrating spatial and non-spatial information and providing a route analysis function. The function was developed to find optimal haul route that comprehensively considered many factors of haul efficiency such as traffic volume, restricted traffic areas, complaints, and signalized intersections during earthworks in urban area. In summary, this paper discusses: (1) the fundamental concept of spatial analysis used in the study for finding the best route that maximizes haul efficiency; (2) a method to reflect the factors affecting haul efficiency on a GIS application; (3) the results of a comparison of really used route and the route recommended by the system.

2. FACTORS AFFECTING HAUL EFFICIENCY

Literature review and expert interviews were conducted to find out factors affecting haul efficiency. It was revealed that the factors were time slots, complaints caused by noise, dust, and vibration, traffic regulation such as restricted area of dump trucks, and signalized intersections. First, haul efficiency largely decreases during rush hours due to traffic congestion, and the plan without considering rush hour may cause schedule delay. Also, in the case that dump trucks go through residential and school area, complaints can be made by noise, dust, vibration, and traffic accidents. It was revealed by expert interviews that complaints are not really considered when route planning. In addition, traffic regulation such as restricted area of dump trucks affects the efficiency. For example, dump trucks weighing more than 32tons are not allowed to enter Won-hyo Bridge and Young-dong Bridge, and the trucks cannot use Olympic Road from Ha-il interchange to Haeng-ju Bridge between 07:00 A.M. – 10:00 A.M. Finally, haul efficiency can be affected by the number of signalized intersections. It was also revealed that truck drivers prefer a road without signalized intersections even though they drive further because the road without signalized intersections takes shorter time. Other factors are hillness and surface condition of a road, but they were excluded because they do not affect a lot in this study.

3. TIME SLOT

Figure 1 shows the change in traffic volume on the average over time of day in Seoul from Jan. 1, 2007 to Dec. 31, 2007, and Figure 2 presents the change in traffic volume over time of day at Ha-an Bridge. The figures demonstrate that the volume drastically increases at around 7:00 A.M. and 6:00 P.M. Figure 3 is real data of haul time acquired from a construction site in Seoul and says that truck cycle time is about 42% more at morning time than the other time. Therefore, time slot 1 was defined as 7:00 A.M. – 10:00 A.M. and time slot 2 10:00 A.M. – 6:00 P.M.

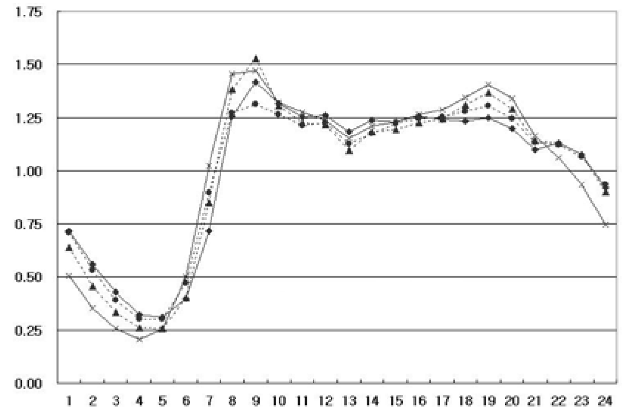


Figure 1. Average Traffic Volume Change in Seoul

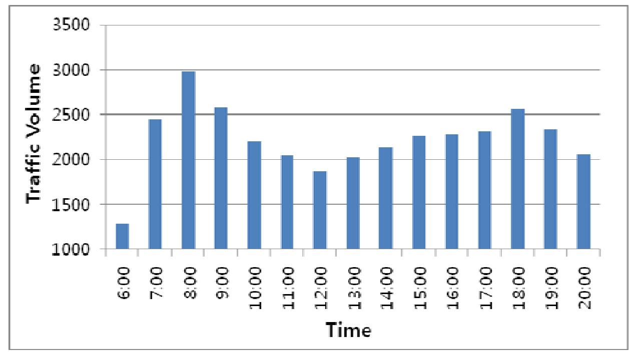


Figure 2. Traffic Volume Change at Ha-an Bridge

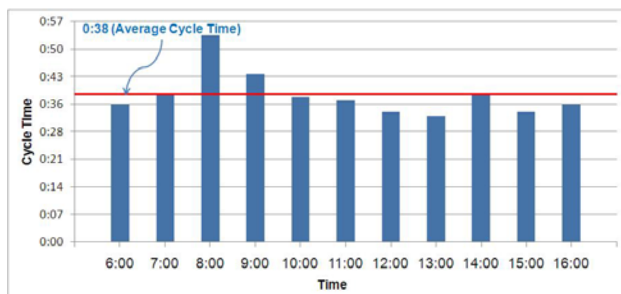


Figure 3. Cycle Time over Time of Day

4. PROCESS MODEL TO FIND THE BEST HAUL ROUTE USING GIS

GIS plays an important role in this study by providing and analyzing spatial information of roads, residential and school area, roadways, and locations of signalized intersections. This paper adopted the method that converts various haul speed factors to raster data model and reflects them into account by weighting each cell using ‘Spatial Analyst’ function of GIS. Spatial Analyst can support decisions on complex spatial problems by its unique analysis functions in consideration of many certain entities on raster maps.

The procedure proposed in this study to find the best route is schematically illustrated in Figure 4. At step 1, several features are picked out of digital maps of the site. Roadways, residential & school areas, restricted areas, and locations of signalized intersections are created as CAD drawings. Then, the drawings are converted to raster to create source dataset. Each cell is set to have a value based on the amount of influence on haul speed according to traffic volume per lane per hour, complaints, and signalized intersections. Every raster is weighted and combined to a single set at step 3. Also, information on the location of the origin is input by a user at this step. Cost weighting function is performed on the dataset to get a cost weighted distance map. Finally, now that all data required to find the best route are ready, the user can find the best route by performing Shortest Path function with the information about the location of the destination and direction.

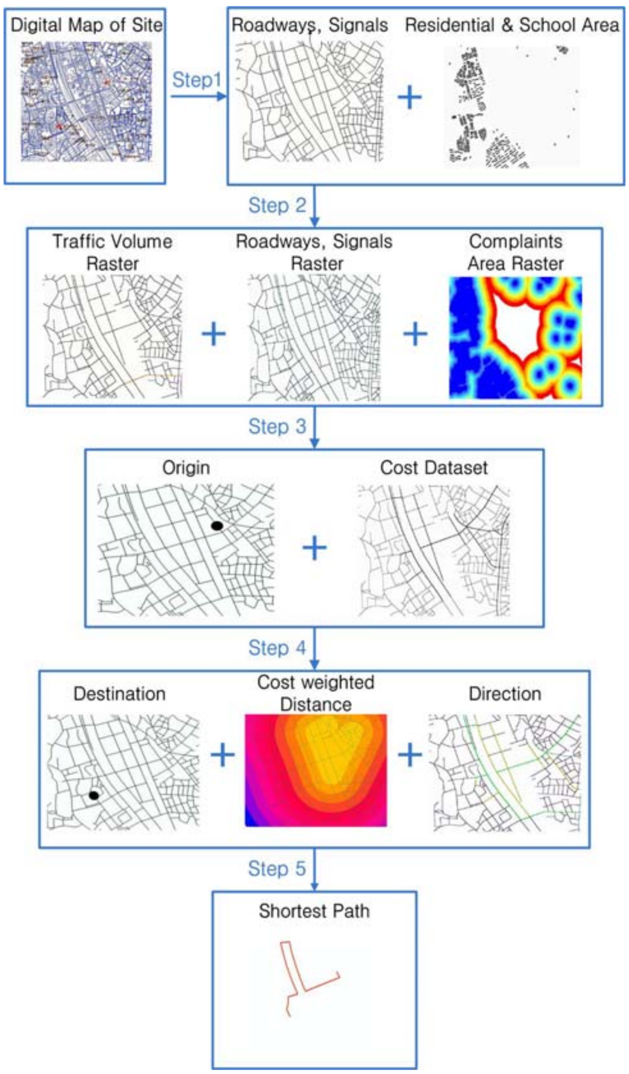


Figure 4. Analysis Procedure

5. CASE STUDY

Case study was conducted by applying the mentioned methodology to a real case of construction site in Seoul. The site is located in Seoul, and the spoil site is located in a sub-urban city called Gwangmyeong-si. The spoil site is about 5km away from the construction site. There is a bridge called Cheol-san Bridge connecting them directly, but dump trucks are restricted to enter the bridge because of weight. So, real work was performed by using Ha-an Bridge located south of Cheol-san Bridge.

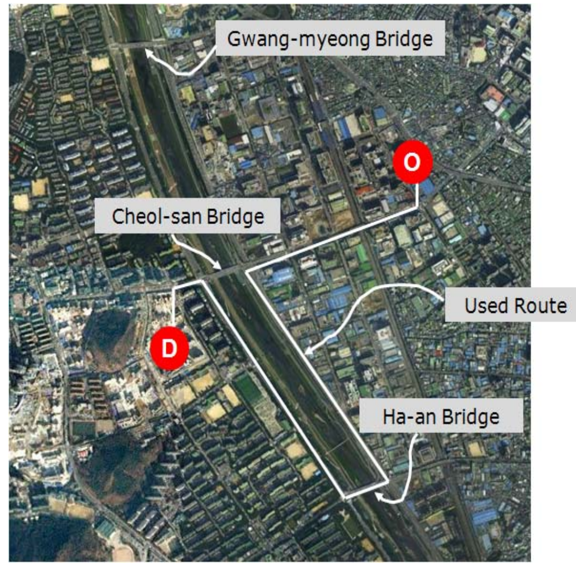


Figure 5. Case Study

5.1 Modeling and Factor Weighting

Traffic volume per lane per hour of each time slot, complaints caused by noise, dust, and vibration around residential and school areas, signalized intersections, and restricted area of dump trucks were considered in this study. As mentioned in the previous section, every factor is modeled as raster dataset, and each dataset is weighted based on how much it affects haul speed. For example, if the site is located in complaint sensitive area, the factor of complaints may be weighted heavily. It was revealed by construction managers' interviews that traffic congestion is the biggest problem in urban area, and they indicated that complaints caused by noise, dust, and vibration need to be considered. Table 1 shows the weight of each factor applied to the case site based on opinions from construction managers. The weights may change depending on where the site is located.

Table 1. Factor Weights

Factor	Weight
Traffic Volume per Lane per Hour	0.50
Complaints	0.25
Number of Signalized Intersections to Pass	0.25
Total	1.00

5.1.1 Traffic Volume and Signalized Intersection

Haul speed decreases as vehicle volume per lane per hour increases and as there are more signalized intersections along the route. The roads and signals are modeled within the GIS as shown in Figure 6. The models can be created from the digital map. Also, roads and signals information can be easily imported from attributes from other sources such as the car navigation system. Ha-an Bridge usually has more traffic volume than Gwang-myeong Bridge as shown in Figure 7. Signalized intersections are, on the average, every 300m.

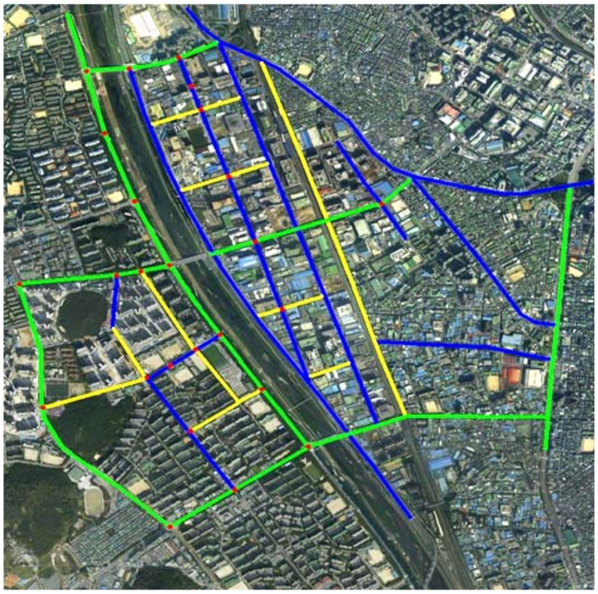


Figure 6. Modeling of Roads and Signals

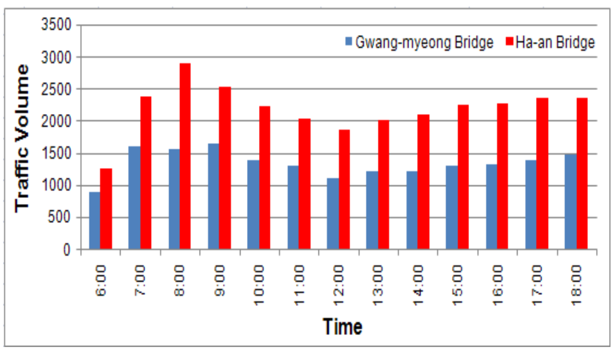


Figure 7. Traffic Volume

5.1.2 Residential & School Areas, Restricted Area

There are large residential and school areas (6 apartment complexes, 8000 housings, and 6 schools) next to the roads to the spoil site as shown in Figure 8. There may be complaints caused by noise, dust, vibration, and safety hazards if trucks use the roads. Therefore, trucks need to avoid using the roads to prevent complaints. To reflect this situation, the classified buffer zone was created as shown in Figure 9.

Cheol-san Bridge is connecting the two sites directly, but dump trucks are restricted to enter the bridge because of weight. So, restricted area is modeled as raster with no value so as for the system to avoid the area when finding the best route.

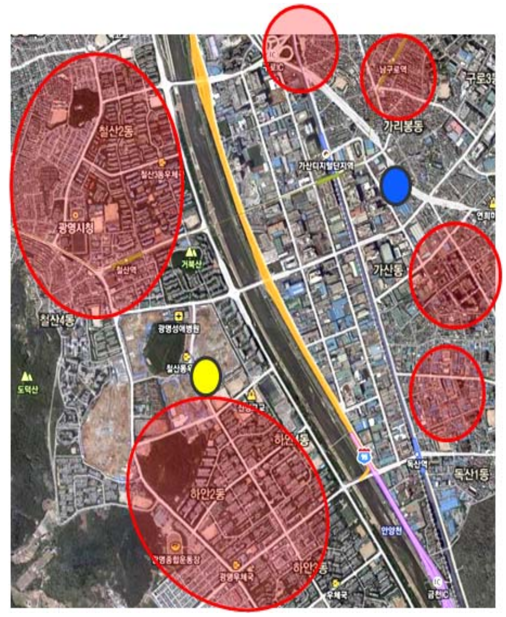


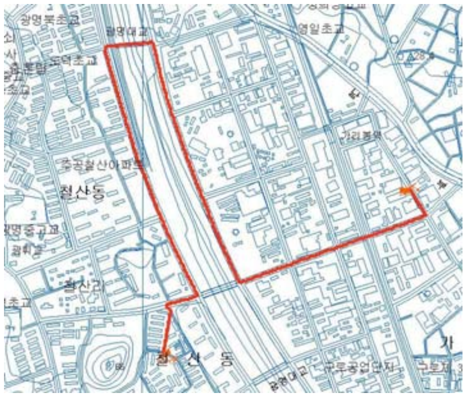
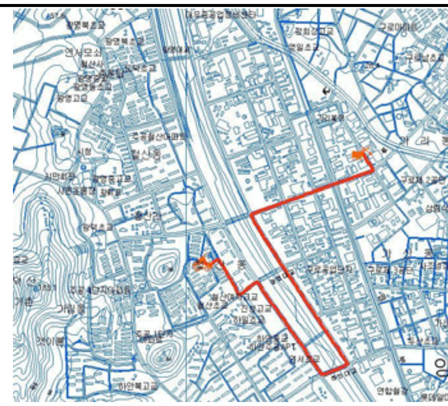
Figure 8. Residential and School Area

Figure 9. Classified Buffer Zone

6. RESULTS AND DISCUSSION

The system found two available routes based on time slots as described in Table 2. It was found that Route 1 is suitable when hauling loaded with earth during time slot 1, and Route 2 when hauling with earth during time slot 2 and returning during time slot 1 and 2. Lots of vehicles flow out of Seoul during time slot 1 via Ha-an Bridge, on the other hand, there are relatively less vehicles passing Gwang-myeong Bridge than Ha-an Bridge. This fact implies that vehicle speed out of Seoul via Gwang-myeong Bridge during time slot 1 should be faster than that of Ha-an Bridge. Actually, it was revealed that average speed passing Gwang-myeong Bridge during time slot 1 is higher than that of Ha-an Bridge.

Table 2. Analysis Results

		Route 1	Route 2
Description			
		-Via Gwang-myeong Bridge -6 lanes (3 lanes Gwang-myeong to Seoul) -Passes 10 signals -Close to residential area -Traffic Volume (vehicles/lane-hour) -Slot 1: flow out (144), flow into Seoul (384) -Slot 2: flow out (213), flow into Seoul (235)	-Via Ha-an Bridge -7 lanes (3 lanes Gwang-myeong to Seoul) -Passes 9 signals -Close to school area -Traffic Volume (vehicles/lane-hour) -Slot 1: flow out (229), flow into Seoul (580) -Slot 2: flow out (247), flow into Seoul (402)
Time Slot 1	Haul	O	
	Return		O
Time Slot 2	Haul		O
	Return		O

7. CONCLUSION

This paper demonstrates that spatial manipulation, route analysis of GIS can be effectively used for haul planning in earthworks. For optimal haul route selection based on time slots, this paper developed a process model for efficient haul route selection using GIS. Many factors can affect dump truck's haul speed in urban area. Traffic volume, complaints caused by dust, noise, and vibration by dump trucks, signalized intersections, and restricted area of dump trucks were considered to find the best route. Time slots were, also, taken into account because haul efficiency largely decreases during rush hours. The slots were classified into two groups: time slot 1 and time slot 2, based on the characteristics of traffic volume change over time of day. A practical case study is then presented to demonstrate the applicability of the proposed approach. Further study of quantitative approach to calculate haul speed for the best route selection should be followed for thorough plan.

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