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Development of a Prototype Model to Establish an Economic Earthwork Plan that Includes the Selection of a Dump Site/Borrow Pit

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Abstract: Earthwork in road construction projects is the major activity that accounts for about 20%–30% of the total construction cost, and the internal/external hauling plan is the key factor for determining the successful completion of the project. However, the hauling plan at the site, which includes the selection of the dump site and borrow pit, is usually determined by the site manager's subjective and empirical discretion alone. Therefore, this study has developed a prototype model that provides the optimal internal/external hauling plan. It includes the determination of the most economical dump sites and borrow pits (location and number) among other candidate sites as well. The transshipment problem theory is incorporated into the optimized algorithm with the consideration of various factors affecting earthwork cost. Direct costs from an optimized transport based on an existing model against another from this model were compared to prove its feasibility. As a result, the reduction of earthwork cost including the dump site/borrow pits reached 4%–8%. This result implies that this prototype model would also be useful in reducing both the earthwork cost and the occurrence of exhaust gas from earthwork equipment by providing optimized transportation paths.

Keywords: linear programming; transportation model; earthmoving logistics; optimization; spoil-bank & borrow pit

1. Introduction

1.1. Background and Objective

Earthwork is carried out by transferring large volumes of soil to create a balance between the existing elevation and the design elevation at the site; its cost accounts for 20%–30% of the total construction cost [1]. Hence, establishing the rational and appropriate soil hauling plan at an early stage is all the more important. However, the internal/external soil hauling plan at the site including the selection of the dump site and borrow pit is heavily dependent on site manager's subjective and empirical discretion alone [2].

The rational hauling plan proposed in previous studies is the route with the lowest value as a result of simply multiplying the hauling distance by hauling volume [3–5]. The studies above are based on a transportation model in a bid to improve the transportation efficiency. The study has been developed to those on a soil hauling method that considers a number of factors (such as worker's resource, budget, indirect cost) based on transportation theory, which further influences road construction [6,7]. The importance of the hauling plan including the dump site/borrow pit failed to be considered in such studies because they only focused on certain influential factors related to road construction [8].

When spoil cannot be accommodated internally at the site, rational determination on the dump site/borrow pit outside the site will be made after reviewing many alternatives. However, it is difficult to come up with a solution that can accommodate internal hauling as well as the hauling to the dump site or borrow pit outside the construction site from an economical standpoint. Since the earthwork is influenced by many factors including cutting, banking and hauling, the site condition of a dump site/borrow pit (location, capacity, and fees), productivity of the earthwork equipment, type of soil, etc.: These various factors must be considered in comprehensive ways for the optimized earthwork plan.

Thus, this study is aimed at developing a prototype model, based on petroleum transportation and the allocation model, that is able to come up with an optimal internal/external hauling plan that is the most economical and sustainable among other candidate sites. This model includes an optimized objective function which considers various influential factors of earthwork as aforementioned and provides the most economical internal hauling plan not only at the site, but also its destination outside the site as well as information on the location of the dump site/borrow pit, and finally, cost.

1.2. Scope of Study and Methodology

The scope of this study focuses on earthwork and the case studies are performed with the prototype model for the site requiring a dump site/borrow pit. This prototype model contains an optimized objective function considering various factors such as the hauling speed inside and outside the site, the location and capacity of dump site and borrow pit, its cost for equipment (dump truck, excavator, loader) the equipment productivity, the type of soil and the measures for an economical soil hauling plan.

Implementation procedure and the model's method of development are as Figure 1.

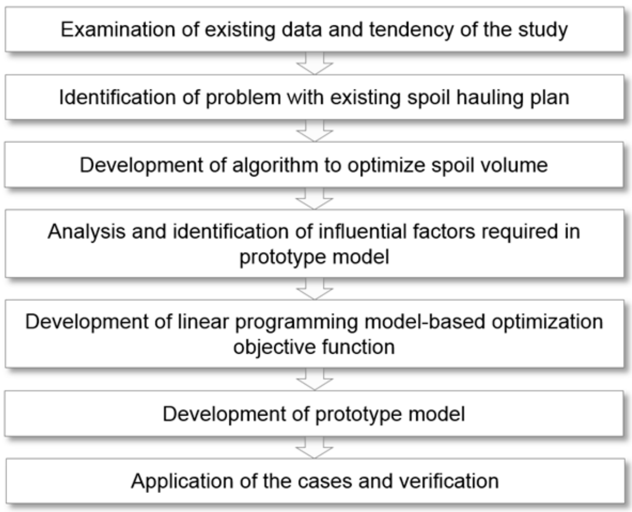


Figure 1. Procedure and method of the study.

An algorithm is developed by applying appropriate methodology and considering influential factors that are included in the entire process of the soil hauling plan in a bid to develop the prototype model that incorporates a hauling plan (including the selection of dump site/borrow pit) for earthwork inside and outside the site. Influential factors will include total earthwork volume, total length, productivity of equipment, recyclable earthwork volume, hauling distance and speed, which the prototype to be developed will all include. The internal and external earthwork hauling plan and dump site/borrow pit selection will be produced as an outcome of the prototype model. Moreover, the outcome of the model and road constriction will be compared to each other through the application of case studies and their verifications, thereby supporting the conclusion from the study.

2. Theoretical Review

2.1. Trend of Related Studies

Previous studies with earthwork mainly focus on how to haul the soil in an efficient and economic way. This study will address the following: (1) Optimal method considering work volume and distance; (2) optimal hauling method considering the volume to be transported outside the site considering the dump site/borrow pit; (3) optimum method based on nonlinear earthwork considering many influential factors in the process of earthwork.

The study on optimal hauling started in earnest by Mayer [3] and Easa [4,5] which focused on shortening the hauling distance at the site so as to haul excavated and banking soil over reduced distance. These studies paved the foundation to optimize the earthwork volume in various ways.

Son [9] proposed the alternative to minimize the volume for hauling by developing the mathematical model that determines the direction to haul the excavated soil from the site and Ji [10] developed the spoil hauling model that considers work sequence using a binary integer programming. Such studies seem to be proper in seeking an alternative to transport the earthwork volume in a balanced way, but are considered inappropriate in developing a hauling plan with a plural number of undetermined dump sites or borrow pits for a large road construction project.

Park [8] developed a model to determine the dump site by predicting the carbon emission of the site through network analysis from an environmental point of view. In selecting the candidate sites, distance, approach route, and land acquisition cost were considered thus, making the study more reliable.

Hassaneen [11] proposed a detailed model for assessing the energy consumption and CO_2 emissions of selected hauling fleets by using an existing hauling planning program such as DynaRoad. In this research, this hauling planning program uses data on the productivity of selected haulers and the amount of materials to be hauled during cutting, filling, borrowing, and disposal operations and develops an earthwork schedule. However, this program does not focus on the selection of the most economical number and locations of borrow pits and spoil banks among multiple potential places.

Such a model is intended to reduce the carbon emission which is important to environmental conservation. Although the model is used for the site generating the spoil, the transport within the site was yet to be considered.

Moselhi [6] conducted a study to minimize the earthwork volume and developed the model for decision-making by the worker to effectively carry out the earthwork in a practical way considering various factors that may influence spoil-hauling such as a worker's resource, budget, soil characteristics, indirect cost and equipment characteristics. The model however, has a limit in use for hauling within the site because nonlinear programming which is rather more complex was used instead of linear programming in the process of calculating many factors. Nassar [7] minimized the spoil hauling volume by applying the work sequence which is not considered in previous studies to the model, making use of linear programming. The result of using linear programming is not necessarily superior to the value from nonlinear programming, but it could produce more intuitive output in dealing with the problem as well as reduce the probability of distortion in the optimization process.

In conclusion, previous studies have shown that it is more important to establish rational and cost efficient spoil hauling plans in road constriction. Rather than focusing only on internal banking/cutting volume, it is necessary to consider both the internal and external hauling with several candidate dump sites and borrow pits and provide the information necessary for establishing the optimal hauling plan. Therefore, making a more practical hauling model applied by linear programming that considers various influential factors such as hauling speed, equipment capacity and quantity, type of soil, work efficiency and the capacity of a dump site and borrow pit must be attempted.

2.2. Transshipment Transportation Model Theory

The transportation model was developed in a bid to transport the product or service from multi suppliers to multi destinations. A prototype model was developed using a transshipment transportation model for establishing an optimized spoil hauling plan including the internal/external hauling plan and selection of the dump site/borrow pit.

A transshipment transportation model has the node between the supply source and destination such as a site entrance which is considered a phasing distribution. Figure 2 indicates the combination of the routes from the supply source (cutting site) to the destination (banking site) and a multi supply source ($S_1, S_2, \cdots, S_m$) is linked to multi destinations ($D_1, D_2, \cdots, D_n$) via interim points ($T_1, T_2, \cdots$).

$$\begin{aligned} \text{MinZ} = \text{DST}_{11}x_{11} &+ \text{DST}_{12}x_{12} + \text{DST}_{21}x_{21} + \text{DST}_{22}x_{22} + \text{DST}_{31}x_{31} + \text{DST}_{32}x_{32} \\ &+ \text{DTD}_{11}y_{11} + \text{DTD}_{12}y_{12} + \text{DTD}_{13}y_{13} + \text{DTD}_{14}y_{14} + \text{DTD}_{21}y_{21} \\ &+ \text{DTD}_{22}y_{22} + \text{DTD}_{23}y_{23} + \text{DTD}_{24}y_{24} \end{aligned} \quad (1)$$

$$\begin{aligned} \text{st.}\ x_{11} + x_{12} &\le S_1 \\ x_{21} + x_{22} &\le S_2 \\ x_{31} + x_{32} &\le S_3 \\ x_{11} + x_{21} + x_{31} &= y_{11} + y_{12} + y_{13} + y_{14} \\ x_{12} + x_{22} + x_{32} &= y_{21} + y_{22} + y_{23} + y_{24} \\ y_{11} + y_{21} &\le D_1 \\ y_{12} + y_{22} &\le D_2 \\ y_{13} + y_{23} &\le D_3 \\ y_{14} + y_{24} &\le D_4 \\ x_{ij} \ge 0,\ y_{ij} \ge 0;&\ i,\ j = 1,\ 2,\ 3,\ 4 \end{aligned}$$

where Z is object function (hauling distance, minimum hauling volume), S_i is the volume that could be supplied from supply source (m^3), D_j is the volume that could be accommodated at the destination (m^3). x_{ij} is the volume from the supply source to interim point (T_1, T_2) (m^3); y_{ij} is the volume from interim point (T_1, T_2) to the destination (m^3). DST_{ij} is hauling distance from S_i toT_j (m), DTD_{ij} is hauling distance from T_i to D_j (m).

Equation (1) is the mathematical model of transshipment transportation and its constraint conditions are that: (1) the volume from the supply source to the interim point will be equal to or less than the maximum volume that can be supplied from the supply source; (2) the interim point serves as the passage for transportation and thus the volume from the supply source (cutting site) shall be all sent to the destination (banking site); (3) the volume required by the destination (banking site) shall be transported from the interim point and thus, the constraint condition to the destination is required. Viewing such constraint conditions, the equation which serves as a base for the spoil hauling plan was established. Using the conditional equation of transshipment transportation, the objective function classified based on the interim point was established to be the total cost of internal hauling and external hauling (including information on dump site, borrow pit). The total cost of internal and external hauling can be calculated in consideration of the data on productivity of equipment and fees for the candidate dump site/borrow pit.

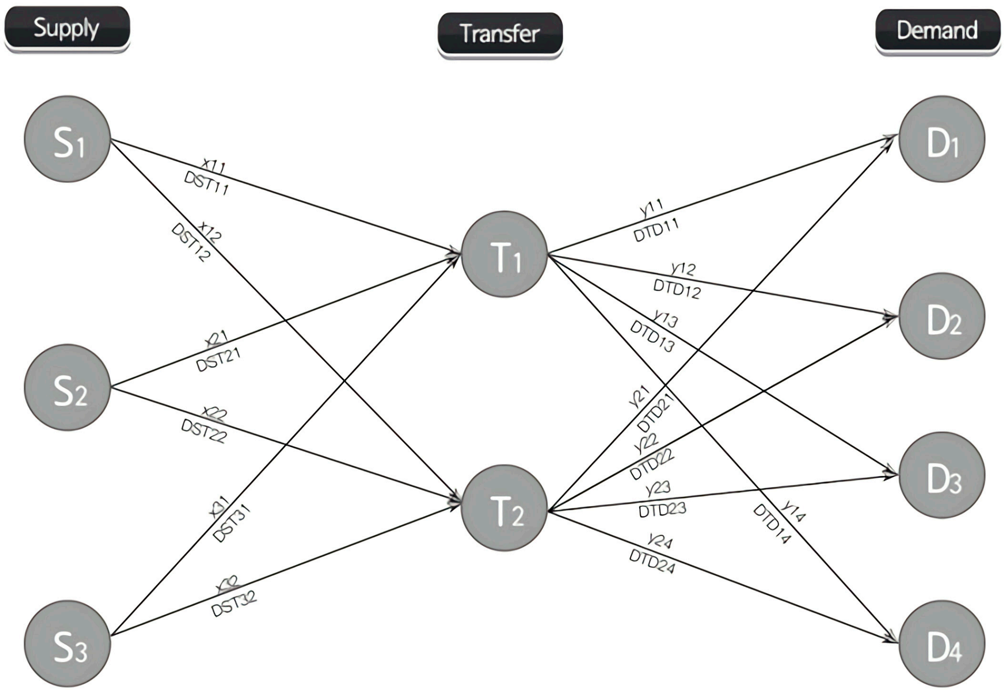


Figure 2. Transshipment transportation model route.

3. Development of Prototype Model for Establishing Optimal Spoil Hauling Plan

3.1. Algorithm for Optimizing Earthwork Hauling Plan

Earthwork is generally divided into excavation, loading, hauling, banking, tamping and embankment laying. Earthwork hauling is then classified into no hauling, hauling by dozer, or hauling by dump truck. Figure 3 is the earthwork hauling plan algorithm showing the process of determining the internal and external hauling plan and the determination of a dump site/borrow pit. It is necessary to analyze the earthwork data for road construction. At this stage, analysis of a specific section is carried out using a drawing and the earthwork volume sheet as well as the estimate of cutting/banking volume shall be completed drawing data. When the estimate is completed, no-charge hauling is performed at the boundary after dividing the section by 20 m in accordance with the design guideline for national road construction. Afterwards, the residual cutting/banking volume shall be re-calculated for dozing and the section will be divided by 60 m considering the dozer's work efficiency to establish ta hauling plan by a dozer. Hauling by a dozer is performed at the boundary between banking and cutting section after dividing the section by 60 m, but this volume is variable depending on the base for division. Thus, it is classified into 3 alternatives based on a base for division by 60 m as (① STA. 0 + 000–STA. 0 + 060; ② STA. 0 + 000–STA. 0 + 020, STA. 0 + 020–STA. 0 + 080; ③ STA. 0 + 000–STA. 0 + 040, STA. 0 + 040–STA. 0 + 100) and thus, the hauling optimization process is performed.

Hauling over 60 m shall be planned using the dump truck instead of the dozer. Heavy equipment used for the hauling by a dump truck includes the excavator, loader and dump truck; information necessary for each equipment operation shall be input. For optimization, the constraint condition of the equipment depending on the site condition shall also be input. Constraint conditions include capacity by equipment, minimum hourly cost considering the Q value (equipment productivity data (m^3/h)), the minimum value of volume for hauling, and the limit in maximum capacity by section. After finishing such a process, optimization of the earthwork hauling plan uses the value-seeking program. Then, the objective function concludes the minimum value of total cost considering the data on the dump site/borrow pit. As a result of optimization, internal/external hauling cost and the optimal dump site/borrow pit are determined. Thus, the optimum hauling prototype model is developed through the earthwork volume algorithm.

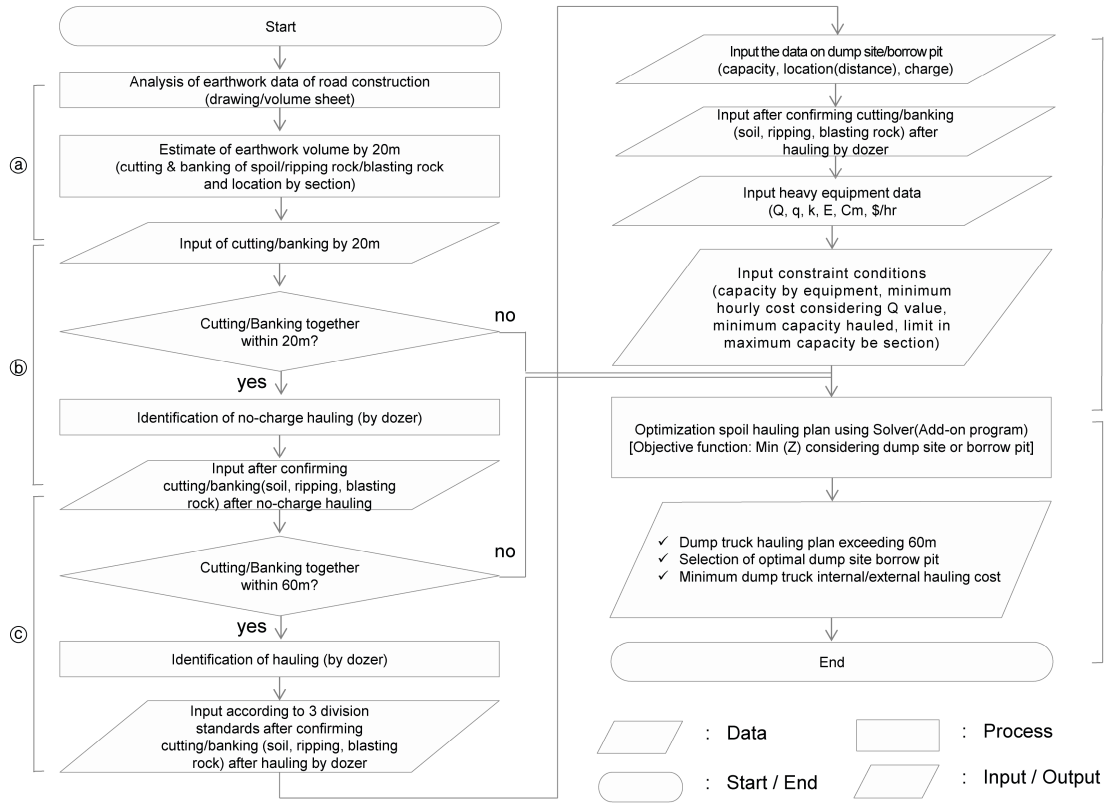


Figure 3. Algorithm for optimizing earthwork hauling plan.

3.2. Influential Factors and Objective Function of Optimal Process Model for Earthwork Hauling Plan

3.2.1. Influential Factors

The earthwork optimization process model includes hauling the distance by section, the equipment's cycle time, hauling volume, travel speed, earthwork equipment's productivity data, distance to dump site/borrow pit and fees for use. The transshipment transportation theory-based optimization objective function value was set as the total construction cost (expenses of dump truck, excavator, loader and fees using for dump site/borrow pit) in consideration of the Design Guideline for National Road Construction and the Price Information Gazette. In addition, other influencing factors, which include on-site environmental and physical conditions such as crusher, other earthwork equipment, any limited earthwork planning conditions, and weather conditions, can be added if these factors affect to estimate the earthwork costs.

The hauling volume within the site, hauling to/from the dump site/borrow pit which is considered external hauling and the determination of a dump site/borrow pit can be confirmed through the optimization mode.

Table 1 below includes influential factors included in the optimization hauling plan process model that contains the recyclable ratio of soil, volumetric conversion factor, work efficiency, equipment's cycle time, and vehicle speed at site when loaded and when empty, which are classified as follows.

Table 1. Influential factors relating to earthwork hauling plan.

Factor	Equipment
F (volumetric conversion factor), E (work efficiency), Cm (one cycle time (s)), q (bucket capacity), K (bucket coefficient), t_1 (time to fill bucket with spoil), t_2 (Basic time such as gear change and time till following equipment arrives)	Loader
F (volumetric conversion factor), E (work efficiency), Cm (one cycle time (s)), q (bucket capacity), K (bucket coefficient)	Excavator
Q (loading capacity of dump truck), f (volumetric conversion factor), E (work efficiency), Cm (one cycle time (m)), Es (work efficiency of loader), n (cycle of loading machine to finish loading a dump truck), t_1, t_2, t_3, t_4, and t_5 (components of one cycle time; m), hauling road and mean travel speed (V1, V2, V3, V4)	Dump truck
Capacity of dump site/borrow pit, hauling distance, recyclable soil ratio	Others

3.2.2. Objective Function

The sum of the hauling cost and fees of a dump site/borrow pit among earthwork cost is set as the objective function in this study. The objective function includes productivity of earthwork equipment (dump truck, excavator, loader) hauling distance at the site, hauling distance to dump site/borrow pit and the fees for dump site/borrow pit. Equipment productivity data includes hourly production, capacity of dump truck, volumetric conversion factor, work efficiency; a cycle time and travel speed at the site and travel time to a dump site/borrow pit are also included in an objective function. A more specific explanation is in Equations (2)–(6) [12].

Equation (2) below indicates the hourly capacity of the dump truck which is necessary to optimize the hauling plan in consideration of labor and expense of the dump truck as well as the material and hauling volume.

$$Q = \frac{60 \times q \times f \times E}{Cm} \tag{2}$$

where Q is hourly capacity of dump truck (m^3/h), q is loading capacity of dump truck in bulk (m^3), f is volumetric conversion factor, E is work efficiency (dump truck: 0.9), Cm is a cycle time (m).

Equation (3) below indicates the hourly capacity of a loader. The cost of hauling by a loader is estimated in consideration of labor cost, material cost, expenses and hauling volume.

$$Q = \frac{3600 \times q \times K \times f \times E}{Cm} \tag{3}$$

where Q is loader's hourly capacity (m^3/h), q is bucket capacity (m^3), K is bucket coefficient, f is volumetric conversion factor, E is work efficiency, Cm is a cycle time (s).

Equation (4) below indicates the hourly capacity of an excavator. As the equipment to haul the blasted spoil, the cost of hauling by an excavator is estimated in consideration of the labor cost, material cost, expenses and hauling volume.

$$Q = \frac{3600 \times q \times K \times f \times E}{Cm} \tag{4}$$

where Q is excavator's hourly capacity (m^3/h), q is ripper or bucket capacity (m^3), K is ripper or bucker coefficient, f is volumetric conversion factor, E is work efficiency, Cm is a cycle time (s).

Based on an equation indicating the hourly capacity of equipment, the type of soil (soil, ripping rock, blasting rock), the fees for a dump site/borrow pit and the sum of direct construction cost are set as an objective function and thus, the earthwork hauling plan optimization model is developed. Using this model, the most cost efficient dump site/borrow pit and hauling route can be determined. Equation (5) is for the labor cost among the equipment expense of the dump truck for internal hauling.

Labor costs in the hauling costs by dump trucks for the section can be estimated in a way by multiplying hourly labor costs of dump trucks by the hourly dump truck capacity.

$$\sum \text{SDL(Soil)} = \text{SDL} \div \frac{60 \times \text{q} \times \text{f} \times \text{E}}{(\text{t}_1 + \frac{\text{SHD}}{\text{V1}} + \frac{\text{SHD}}{\text{V2}} + \text{t}_3 + \text{t}_4 + \text{t}_5)} \times \text{Q}_i \quad (5)$$

where, SDL (on-Site Dump Labor cost) is hourly dump truck labor cost at site ($/h), SHD (on-Site Haul Distance) is hauling distance at the site (m), q is the capacity per load on dump truck without compaction (m^3), f is volumetric conversion factor, E is work efficiency, V1 is a mean travel speed at the site when loaded (km/h), V2 is a mean travel speed at the site when empty (km/h), t_1 is loading time of dump truck (m), t_3 is dumping time (m), t_4 is the time between arrival at loading point and start of loading (m), t_5 is the time to install and removal of the load box cover (m), Q_i is earthwork volume at the section (within 60 m) (m^3).

Equation (6) below is intended to estimate the labor costs of dump truck expenses for hauling spoil outside the site. The travel speed to a dump site/borrow pit (V3, V4) and hauling distance (OHD) can be input as a variable and from that, the labor cost of the dump truck expense can be obtained.

$$\sum \text{ODL(Soil)} = \text{ODL} \div \frac{60 \times \text{q} \times \text{f} \times \text{E}}{(\text{t}_1 + \frac{\text{OHD}}{\text{V1}} + \frac{\text{OHD}}{\text{V2}} + \frac{\text{OHD}}{\text{V3}} + \frac{\text{OHD}}{\text{V4}} + \text{t}_3 + \text{t}_4 + \text{t}_5)} \times \text{Q}_i \quad (6)$$

where, ODL (Off-site Dump Labor Cost) hourly labor cost of dump truck for hauling outside the site ($/h) and OHD (Off-site Haul Distance) is hauling distance outside the site (m), q is the capacity per load on dump truck without compaction (m^3), f is volumetric conversion factor, E is work efficiency, V1 is a mean travel speed at the site when loaded (km/h), V2 is a mean travel speed at the site when empty (km/h), V3 is a mean travel speed outside the site when loaded (km/h), V4 is a mean travel speed outside the site when empty (km/h), t_1 is loading time of dump truck (m), t_3 is dumping time (m), t_4 is the time between arrival at loading point and start of loading (m), t_5 is the time to install and removal of the load box cover (m), Q_i is earthwork volume at the section (within 60 m) (m^3).

Using such equations, the objective function includes the least sum of internal and external labor costs, material costs and expenses of dump truck, loader and excavator and the fees for a dump site/borrow pit. A dump site/borrow pit shall be able to accommodate the excavated spoil or required spoil because the prototype model is developed based on a linear program. This model indicates the most economical earthwork hauling cost, hauling route by section, and designation of the dump site/borrow pit.

Figure 4 shows the objective function and influential factors used in the prototype model. The objective function is the minimal sum of internal and external labor cost, material cost and expenses of dump truck, loader and excavator and the fees for a dump site/borrow pit. As aforementioned, each of these 4 elements includes the travel speed within the site and outside the site, hourly capacity, type of soil, work volume and work efficiency. The sum of each of the 4 elements has the result value in cost and selects the optimal alternative among several other candidate dump sites/borrow pits.

The solver of company F was used in obtaining the optimum solution of this objective function. Figure 5 shows an input window such as Objective, Variables, and Constraints to drive the solver. When implementing the solver using a linear program, the value considering the cost efficiency is obtained. When the capacity is available by a candidate dump site/borrow pit, it may be set as a constraint condition. Because of the characteristic of a solver, the result of solution-seeking at the minimum cost can only be identified with the result value.

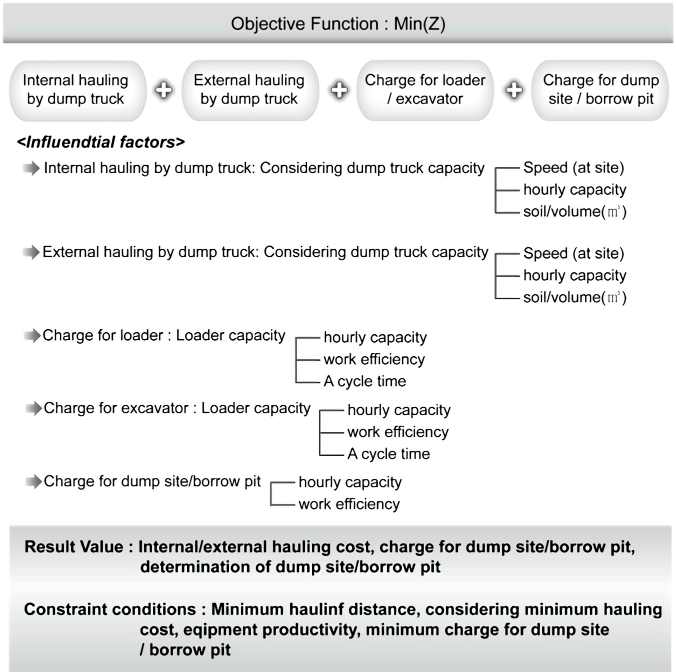


Figure 4. Influential factors within objective function.

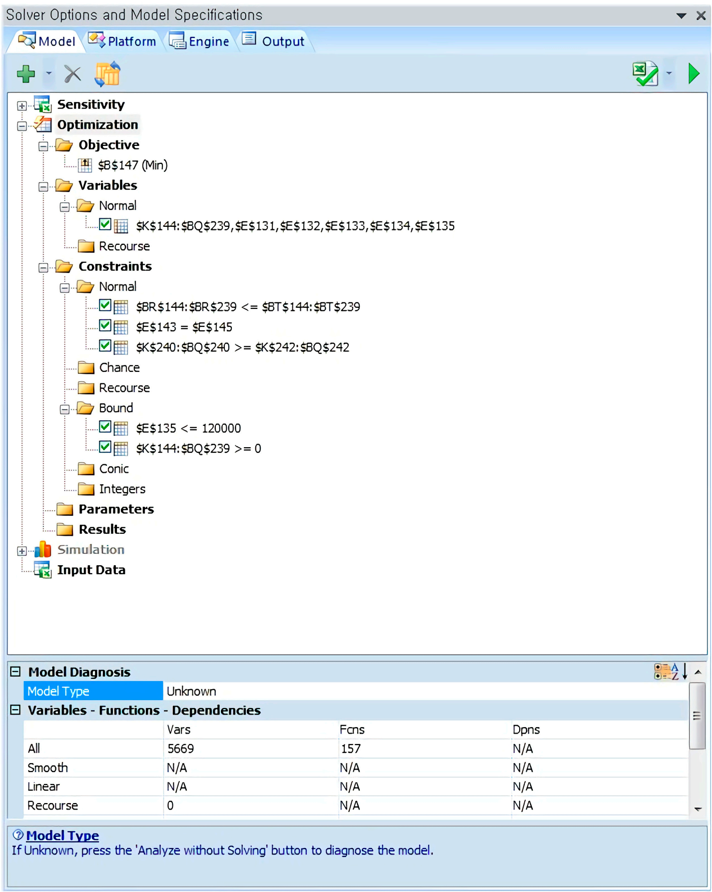


Figure 5. Solver's function.

3.3. Development of Prototype Model for Earthwork Hauling Plan

To explain the Spread Sheet-based optimal prototype model, the earthwork volume optimization process is hereby introduced with this case study. At earthwork volume confirmation and division stage as the initial stage for the earthwork hauling plan prototype model, cutting and banking volume are estimated with the earthwork volume curve after dividing the entire road work by 20 m. Based on this, no-charge hauling is carried out within 20 m and then hauling by a dozer is carried out at a 60 m section.

Figure 6 (corresponding to ⓐ and ⓑ in Figure 3) shows the no-charge hauling when cutting (spoil) 48 m^3 and banking 272 m^3 are at the same location as ① and as ② in Figure 6, cutting 48 m^3 is for no-charge hauling. When no-charge hauling is done, 224 m^3 of banking only will remain at STA. 0 + 12. After applying such no-charge hauling to the entire section, the volume that still remains within 20 m shall be hauled by a dozer after dividing by 60 m.

Such a division by 60 m is in accordance with the guideline for the design practice for road construction in which division by 60 m is said to be the most effective when hauled by dozer. However, dividing by 60 m is dependent on a manager's discretion considering the site condition and its equipment capacity. In this study, the data divided by 20 m according to earthwork volume table is divided into 3 kinds as Alt (1) STA. 0 + 000–STA. 0 + 060; (2) STA. 0 + 000–STA. 0 + 020, STA. 0 + 020–STA. 0 + 080 and (3) STA. 0 + 000–STA. 0 + 040, STA. 0 + 040–STA. 0 + 100 and then by 60 m before an optimizing earthwork hauling plan.

As ③, ④ and ⑤ in Figure 7 (corresponding to ⓒ in Figure 3), the hauling volume by dozer varies depending on an alternative for division by 60 m. When cutting and banking volume exist together within a 60 m section, hauling by a dozer is carried out.

The section is divided by 60 m and the central distance of the section is based on a central line of the length by section (ex, central distance of C1section is 0.03 km(STA. 0 + 00–STA. 0 + 06) where the central distance of F2 section is 0.09 km (STA. 0 + 06 – STA. 0 + 12). When it comes to candidate dump site 2, 0.3 km means the entrance/exit of the site is at STA. 0 + 300 and candidate dump site 2 is 1 km away from STA. 0 + 300 (entrance/exit of the sit). When it comes to candidate dump site 1, candidate dump site 1 is 0.9 km away from STA. 0 + 000.

ⓐ

Station	Cut-Volume(㎥)			Fill-Volume(㎥)
	Soil	Reaping	Blasting	
STA. 0+00	-	-	-	-
STA. 0+02	-	-	-	-
STA. 0+04	16	-	-	-
STA. 0+06	14	-	-	-
STA. 0+08	14	-	-	-
STA. 0+10	-	-	-	100
STA. 0+12	48	-	-	272 ①
STA. 0+14	-	-	-	616
STA. 0+16	-	-	-	1,012

ⓑ

Station	L≤20 Transport Volume(㎥)			Fill-Volume(㎥)
	Soil	Reaping	Blasting	
STA. 0+00	-	-	-	-
STA. 0+02	-	-	-	-
STA. 0+04	-	-	-	-
STA. 0+06	-	-	-	-
STA. 0+08	-	-	-	-
STA. 0+10	-	-	-	100
STA. 0+12	48	-	-	224 ②
STA. 0+14	-	-	-	616
STA. 0+16	-	-	-	1,012

Figure 6. Earthwork volume table within 20 m and hauling by dozer.

ⓒ

<table>
<tr><th rowspan="2">Station</th><th colspan="3">L≤60 Transport Volume(㎥)</th><th rowspan="2">Fill-Volume(㎥)</th></tr>
<tr><th>Soil</th><th>Reaping</th><th>Blasting</th></tr>
<tr><td>STA. 0+00</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td></tr>
<tr><td>STA. 0+02</td></tr>
<tr><td>STA. 0+04</td></tr>
<tr><td>STA. 0+06</td><td rowspan="3">28</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">72 ③</td></tr>
<tr><td>STA. 0+08</td></tr>
<tr><td>STA. 0+10</td></tr>
<tr><td>STA. 0+12</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">1,852</td></tr>
<tr><td>STA. 0+14</td></tr>
<tr><td>STA. 0+16</td></tr>
</table>

<table>
<tr><th rowspan="2">Station</th><th colspan="3">L≤60 Transport Volume(㎥)</th><th rowspan="2">Fill-Volume(㎥)</th></tr>
<tr><th>Soil</th><th>Reaping</th><th>Blasting</th></tr>
<tr><td>STA. 0+00</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>STA. 0+02</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td></tr>
<tr><td>STA. 0+04</td></tr>
<tr><td>STA. 0+06</td></tr>
<tr><td>STA. 0+08</td><td rowspan="3">14</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">184 ④</td></tr>
<tr><td>STA. 0+10</td></tr>
<tr><td>STA. 0+12</td></tr>
<tr><td>STA. 0+14</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td></tr>
<tr><td>STA. 0+16</td></tr>
</table>

<table>
<tr><th rowspan="2">Station</th><th colspan="3">L≤60 Transport Volume(㎥)</th><th rowspan="2">Fill-Volume(㎥)</th></tr>
<tr><th>Soil</th><th>Reaping</th><th>Blasting</th></tr>
<tr><td>STA. 0+00</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">- ⑤</td></tr>
<tr><td>STA. 0+02</td></tr>
<tr><td>STA. 0+04</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td></tr>
<tr><td>STA. 0+06</td></tr>
<tr><td>STA. 0+08</td></tr>
<tr><td>STA. 0+10</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">940</td></tr>
<tr><td>STA. 0+12</td></tr>
<tr><td>STA. 0+14</td></tr>
<tr><td>STA. 0+16</td><td>-</td><td>-</td><td>-</td><td>1,012</td></tr>
</table>

Figure 7. Earthwork volume table within 60 m and hauling by dozer.

Figure 8 (corresponding to ⓓ in Figure 3) is the earthwork volume table for developing the earthwork hauling plan optimization process model, showing soil, ripping rock, blasting rock, banking volume and the distance by section. For instance, section distance of C1 is 0.06 km with cutting volume (soil) 16 m^3 and section distance of F2 is 0.06 km with banking volume 72 m^3. In this Study, 2 candidate dump sites are assumed to be available and the earthwork hauling plan optimization prototype model considering hauling distance (ex, 0.6 km between C1 and F11), hauling volume, and cost is fully demonstrated.

ⓓ

Section	Cutting Volume(㎥)			Banking Volume(㎥)	Distance (km)
	Soil	Ripping	Blasting		
C1	16	-	-	-	0.03
F2	-	-	-	72	0.09
F3	-	-	-	1,852	0.15
C4	342	34	-	-	0.21
C5	645	512	38	-	0.27
F6	-	-	-	846	0.33
F7	-	-	-	642	0.39
C8	-	-	20,685	-	0.45
F9	2,996	-	6,342	-	0.51
F10	-	-	-	1,626	0.57
F11	-	-	-	5,592	0.63
Dump Site1				-	- 0.90
Dump Site2				-	0.30 1.00

Figure 8. Earthwork table of dump truck hauling model.

The whole construction site is at STA. 0 + 000–STA. 0 + 660 (total length 0.6 km) and candidate dump site 1 is assumed to be 0.9 km away from STA. 0 + 00 and candidate dump site 2 is assumed to be 1 km away from STA. 0 + 30. Figure 9 below shows hauling distance by section. For instance, distance from C1 to candidate dump site 1 is 0.93 km and distance between C1 and candidate dump site 2 is 1.27 km.

Hauling Distance(km)	F2	F3	F6	F7	F9	F10	F11	Dump site 1	Dump site 2
C1	0.06	0.18	3.42	3.78	4.68	6.36	6.66	7.14	8.28
C4	0.18	0.06	3.18	3.54	4.44	6.12	6.42	6.90	8.04
C5	0.30	0.18	3.06	3.42	4.32	6.00	6.30	6.78	7.92
C8	0.36	0.24	3.00	3.36	4.26	5.94	6.24	6.72	7.86

Figure 9. Hauling distance by section.

Figure 10 (corresponding to ⓔ in Figure 3) is the optimization result value of Study Model which summarizes the hauling volume between sections and the sum of the construction cost (cost for excavator, dozer and dump truck, fees for dump site/borrow pit) and hauling by section. The result value of the objective function is the minimum value of the sum including expenses relating to hauling by a dump truck and fees for a dump site/borrow pit in Figure 8.

With a result value obtainable from this case study, the earthwork hauling plan by section (including C1→dump site 1, C8→F11), the hauling to dump site, and the cost for hauling by excavator, dozer and dump truck can be checked.

When it comes to candidate dump site 1, the spoil disposal cost is estimated at \$4.08/m^3 to \$4.25/m^3. Parts of section (C1, C4, C5) to dump site 1 have shorter hauling sections than dump site 2 and parts of dump site 2 (C8, C9) have shorter hauling distances than dump site 1.

As a result of seeking the solution in this case study, a hauling plan to dump site 1 is more rational in terms of cost efficiency than dump site 2. Blasting spoil in C8 is determined to use dump site 1 instead of dump site 2 which is nearer from the site, because spoil disposal cost (dump site 1: \$4.08/m^3, dump site 2: \$4.25/m^3) and dump truck cost of dump site 1 are lower than dump site 2, which is closer from the site. Yet, when the cost is similar, dump site 2 which is closer from the site is more favorable. If a situation arises where the capacity is limited, a plural number of dump sites will be designated to maximize the capacity.

(e)

Quantity(㎥)		F2	F3	F6	F7	F10	F11	*Spoil Bank1*	*Spoil Bank2*
Soil	C1	-	-	-	-	-	-	16	-
Reaping	C1	-	-	-	-	-	-	-	-
Blasting	C1	-	-	-	-	-	-	-	-
Soil	C4	-	-	-	-	-	-	342	-
Reaping	C4	-	-	-	-	-	-	34	-
Blasting	C4	-	-	-	-	-	-	-	-
Soil	C5	-	-	-	-	-	-	645	-
Reaping	C5	-	-	-	-	-	-	512	-
Blasting	C5	-	-	-	-	-	-	38	-
Soil	C8	-	-	-	-	-	-	-	-
Reaping	C8	-	-	-	-	-	-	-	-
Blasting	C8	-	-	-	-	-	1,292	19,393	-
Soil	C9	-	-	-	-	-	2,996	-	-
Reaping	C9	-	-	-	-	-	-	-	-
Blasting	C9	72	1,852	846	642	1,626	1,304	-	-

Cost($)		F2	F3	F6	F7	F10	F11	*Spoil Bank1*	*Spoil Bank2*
Soil	C1	-	-	-	-	-	-	118	-
Reaping	C1	-	-	-	-	-	-	-	-
Blasting	C1	-	-	-	-	-	-	-	-
Soil	C4	-	-	-	-	-	-	2,609	-
Reaping	C4	-	-	-	-	-	-	260	-
Blasting	C4	-	-	-	-	-	-	-	-
Soil	C5	-	-	-	-	-	-	4,965	-
Reaping	C5	-	-	-	-	-	-	3,957	-
Blasting	C5	-	-	-	-	-	-	407	-
Soil	C8	-	-	-	-	-	-	-	-
Reaping	C8	-	-	-	-	-	-	-	-
Blasting	C8	-	-	-	-	-	7,382	212,780	-
Soil	C9	-	-	-	-	-	4,669	-	-
Reaping	C9	-	-	-	-	-	-	-	-
Blasting	C9	425	8,328	3,684	2,765	6,928	5,619	-	-

Summarry

From		To	Quantity(㎥)		Distance(km)	Cost($)
C1	→	Spoil Bank1	Soil	16	0.93	118
C4	→	Spoil Bank1	Soil	342	1.11	2,609
C4	→	Spoil Bank1	Reaping	34	1.11	260
C5	→	Spoil Bank1	Soil	645	1.17	4,965
C5	→	Spoil Bank1	Reaping	512	1.17	3,957
C5	→	Spoil Bank1	Blasting	38	1.17	407
C8	→	F11	Blasting	1,292	0.18	7,382
C8	→	Spoil Bank1	Blasting	19,393	1.35	212,780
⋮		⋮	⋮	⋮	⋮	⋮

Figure 10. Earthwork optimization result value.

4. Case Studies

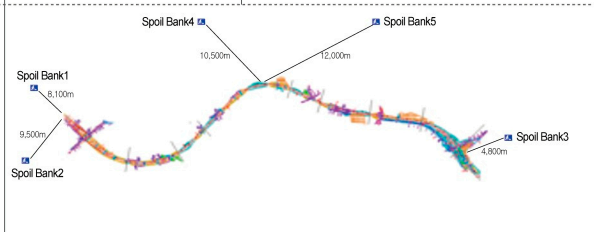
Two domestic road construction sites were selected for case studies to validate the applicability of the proposed model developed in this research study. In the case study 1, the amount of filling material was larger than the one of cutting. On the other hand, in the case study 2, the amount of cutting material was larger than the one of filling. The cost of earthwork including equipment expenses and the fees for a dump site/borrow pit will be compared to the method proposed in the preexisting transportation theory.

4.1. Case Study 1

Case Study 1 is of domestic construction site A requiring spoil as much as 246,281 m^3. The recycling rate considering site requirement is applied as general soil 70%, ripping rock 100% and blasting rock 100%. The total length is 5.13 km and its width is 20 m, which is the average scale among road construction projects and 5 dump sites were selected using MOLIT-provided Earth Information Sharing System [13].

Figure 11 shows 5 candidate dump sites and the locations and fees are as follows: In case of dump site 1, $5.10/$m^3$, 8100 m away from STA. 0; dump site 2, $5.35/$m^3$, 9500 m away from STA. 0. Dump site 3, $5.94/$m^3$, 4800m away STA. 5 + 160; dump site 4, $5.10/$m^3$, 10,500 m away from

STA. 3 + 200. Dump site 5, \$4.25/m^3, 12,000 m away from STA. 3 + 200. As aforementioned in Section 3.3 optimization was carried out with 3 alternatives by applying a 60 m-division method. The average travel speed of a dump truck at a site is 20 km/h when loaded and 25 km/h when empty; beyond the site the speed is 30 km/h when loaded and 35 km/h when empty.

General Information of Earthwork		
Location information	STA. 0+00 ~ STA. 5~13	
Recyclable spoil ratio soil	Soil	70%
	Ripping rock	100%
	Blasting rock	100%
Volume(㎥)	Cutting	897,050㎥
	Banking	650,769㎥
	Spoil	246,281㎥
Candidate Spoil Bank Site		

From	To	Distance	Cost	Limited Quantity
STA. 0+00	Spoil Bank 1	8,100m	\$5.10	350,000㎥
STA. 0+00	Spoil Bank 2	9,500m	\$5.35	More than required spoil at the site
STA. 5+16	Spoil Bank 3	4,800m	\$5.94	More than required spoil at the site
STA. 3+20	Spoil Bank 4	10,500m	\$5.10	More than required spoil at the site
STA. 3+20	Spoil Bank 5	12,000m	\$4.25	120,000㎥

Figure 11. Case Study of Domestic Road Construction on Site A.

Figure 12 shows the result value of the optimal solution (hauling route, volume, dump site) of earthwork hauled by a section obtained by linear programming using Microsoft-Excel and Solver (Frontline System Inc., Incline Village, NV, USA) after imputing each requirement. The result value obtained from this optimized model includes: (1) Determination of dump site; (2) Equipment expense of the project (direct cost of excavator, loader and dump truck); and (3) Hauling route. As a result of seeking the solution through the Solve, candidate dump site 1 was selected among 5 candidate sites. Though the fee of dump site 1 is not the lowest, it is considered to be the most economical when considering all of the influential factors. Thus, the internal earthwork hauling result value was confirmed proving that it is rational to dispose of 262.8 m^3 at C27 by transporting 60.8 m^3 to F2 and 202 m^3 to F26.

To verify the feasibility, the direct construction costs (\$) from an earthwork optimized model and direct hauling costs from existing transportation model were compared.

			F2	F3	F23	F24	F25	F26	F30	Spoil Bank1	Spoil Bank2	Spoil Bank3	Spoil Bank4	Spoil Bank5
Soil	C1	Quantity(㎥)	11.2	-	-	-	-	-	-	-	-	-	-	-
		Distance(km)	0.1											
		Cost($)	5.9	-	-	-	-	-	-	-	-	-	-	-
Reaping	C1	Quantity(㎥)	-	-	-	-	-	-	-	-	-	-	-	-
		Distance(km)												
		Cost($)	-	-	-	-	-	-	-	-	-	-	-	-
Blasting	C1	Quantity(㎥)	-	-	-	-	-	-	-	-	-	-	-	-
		Distance(km)												
		Cost($)	-	-	-	-	-	-	-	-	-	-	-	-
Soil	C27	Quantity(㎥)	60.8	-	-	-	-	202.0	-	-	-	-	-	-
		Distance(km)	1.5					0.06						
		Cost($)	32.2	-	-	-	-	107.0	-	-	-	-	-	-
Reaping	C27	Quantity(㎥)	-	-	-	-	-	107.0	-	-	-	-	-	-
		Distance(km)						0.06						
		Cost($)	-	-	-	-	-	70.7	-	-	-	-	-	-
Blasting	C27	Quantity(㎥)	-	-	-	-	-	891.0	-	-	-	-	-	-
		Distance(km)						0.06						
		Cost($)	-	-	-	-	-	3,066.2	-	-	-	-	-	-
Soil	C28	Quantity(㎥)	-	-	-	-	-	604.0	-	-	-	-	-	-
		Distance(km)						0.12						
		Cost($)	-	-	-	-	-	320.6	-	-	-	-	-	-
Reaping	C28	Quantity(㎥)	-	-	-	-	-	-	-	-	-	-	-	-
		Distance(km)												
		Cost($)	-	-	-	-	-	-	-	-	-	-	-	-
Blasting	C28	Quantity(㎥)	-	-	-	15,331.0	12,151.0	13,963.0	-	-	-	-	-	-
		Distance(km)				0.24	0.18	0.12						
		Cost($)	-	-	-	52,741.0	41,802.0	48,036.5	-	-	-	-	-	-
Soil	C29	Quantity(㎥)	-	-	-	-	-	-	-	-	-	-	-	-
		Distance(km)												
		Cost($)	-	-	-	-	-	-	-	-	-	-	-	-
Reaping	C29	Quantity(㎥)	-	-	18,322.0	6,902.0	-	-	-	-	-	-	-	-
		Distance(km)			0.36	0.30								
		Cost($)	-	-	63,029.0	23,746.0	-	-	-	-	-	-	-	-
Blasting	C29	Quantity(㎥)	-	-	-	-	-	-	-	-	-	-	-	-
		Distance(km)												
		Cost($)	-	-	-	-	-	-	-	-	-	-	-	-
Soil	C34	Quantity(㎥)	-	-	-	-	-	-	-	-	-	-	-	-
		Distance(km)												
		Cost($)	-	-	-	-	-	-	-	-	-	-	-	-
Reaping	C34	Quantity(㎥)	-	-	-	-	-	-	109.0	-	-	-	-	-
		Distance(km)							0.15					
		Cost($)	-	-	-	-	-	-	31.8	-	-	-	-	-
Blasting	C34	Quantity(㎥)	72.0	1,852.0	-	-	-	-	-	-	-	-	-	-
		Distance(km)	1.86	1.80										
		Cost($)	247.0	6,371.0	-	-	-	-	-	-	-	-	-	-
Soil	C83	Quantity(㎥)	-	-	-	-	-	-	-	5,508.0	-	-	-	-
		Distance(km)								13.07				
		Cost($)	-	-	-	-	-	-	-	36,551.0	-	-	-	-
Reaping	C83	Quantity(㎥)	-	-	-	-	-	-	-	2,375.0	-	-	-	-
		Distance(km)								13.07				
		Cost($)	-	-	-	-	-	-	-	15,818.0	-	-	-	-
Blasting	C83	Quantity(㎥)	-	-	-	-	-	-	-	6,051.0	-	-	-	-
		Distance(km)								13.07				
		Cost($)	-	-	-	-	-	-	-	57,122.0	-	-	-	-

From	To	Quantity(㎥)		Distance(km)	Cost($)
C1	F2	Soil	11.2	0.06	5.9
C27	F2	Soil	60.8	1.50	32.2
C27	F26	Soil	202.0	0.06	107.0
C27	F26	Reaping	107.0	0.06	70.7
C27	F26	Blasting	891.0	0.06	3066.2
C28	F26	Soil	604.0	0.24	320.6
C28	F25	Reaping	15,331.0	0.18	52,741.0
C28	F26	Blasting	12,151.0	0.12	41,802.0
C83	Spoil Bank1	Soil	36,551.0	13.05	36,551.0
C83	Spoil Bank1	Reaping	15,818.0	13.05	15,818.0
C83	Spoil Bank1	Blasting	57,122.0	13.05	57,122.0

Figure 12. Analysis of result value of Case study 1.

Figure 13 shows the optimal solution of Alternative 1, 2 and 3 as previously introduced in Section 3.2 (direct hauling cost). For comparison purposes, 3 alternatives for section division were proposed before developing a hauling plan (by a dump truck). As a result of comparing direct hauling cost estimated by the transportation model theory (hauling distance x minimum volume) with direct cost estimated by the model developed in this study, the total cost is reduced by a minimum of 6.78% and a maximum of 8.89%. The result value of Alt 2 among 3 alternatives was most economical in establishing the hauling plan. Thus, section division according to Alt 2 (STA. 0 + 000–STA. 0 + 020, STA. 0 + 020–STA. 0 + 080, see Sections 3.2 and 3.3) is considered to be the most cost efficient.

	Direct hauling cost($) of transportation model (hauling volume x minimum value of hauling distance)	Direct hauling cost($) of earthwork volume optimization model	+/-(%)
Alt 1. Optimum solution	4,203,187	3,838,370	-8.77%
Alt 2. Optimum solution	3,922,218	3,567,050	-6.78%
Alt 3. Optimum solution	4,206,179	3,640,687	-8.89%

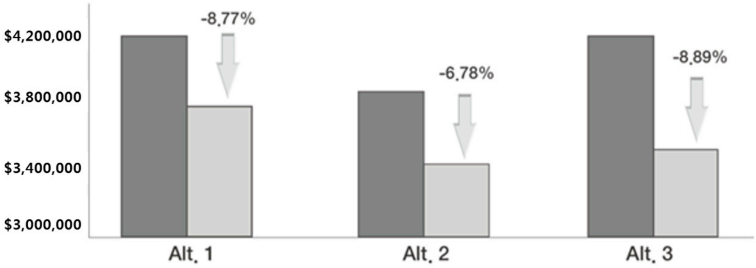
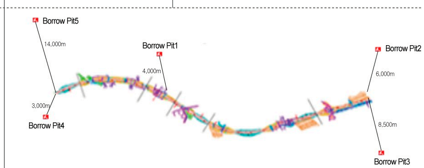


Figure 13. Comparison of result values for Case Study 1.

4.2. Case Study 2

Case study 2 is of domestic construction site B requiring spoil as much as 133,371 m^3. The soil recycling rate is 80% for soil and 100% for ripping rock and blasting rock, which can be selected using the model. The total length is 8.62 km and the width is 20 m which is considered to be of average scale. In addition, 5 dump sites were selected using MOLIT-provided Earth Information Sharing System (www.tocycle.com).

Figure 14 shows 5 candidate dump sites and the locations and fees are as follows: In case of dump site 1, \$14.44/m^3, 4000 m away from STA. 3 + 600, dump site 2, \$13.84/m^3, 6000 away from STA. 8 + 620. Dump site 3, \$14.44/m^3, 8500 m away STA. 8 + 620, dump site 4, \$13.59/m^3, 3000 m away from STA. In addition, in case of dump site 5, \$12.74/m^3, 14,000 m away from STA. 0. The capacity of dump site 5 was limited to 90,000 m^3. The travel speed at the site when loaded is 20 km and 25 km when empty; travel speed outside the site when loaded is 30 km and 35 km when empty.

General Information of Earthwork		
Location information	STA. 0+00 ~ STA. 8~62	
Recyclable spoil ratio soil	Soil	80%
	Ripping rock	100%
	Blasting rock	100%
Volume(㎥)	Cutting	69,804㎥
	Banking	203,175㎥
	Borrow	133,371㎥
Candidate Borrow pit Site		

From	To	Distance	Cost	Limited Quantity
STA. 3+60	Borrow Pit 1	4,000m	$14.44	More than required Borrow at the site
STA. 8+62	Borrow Pit 2	6,000m	$13.84	More than required Borrow at the site
STA. 8+62	Borrow Pit 3	8,500m	$14.44	150,000㎥
STA. 0+00	Borrow Pit 4	3,000m	$13.59	200,000㎥
STA. 0+00	Borrow Pit 5	14,000m	$12.74	90,000㎥

Figure 14. Case Study of Domestic Road Construction on Site B.

Figure 15 summarizes the process of the optimal solution (hauling route, cost, dump site) of earthwork hauled by a section of a linear program using Microsoft-Excel and Solver after inputting each condition. The result value obtained through the earthwork optimization model includes the selection of dump sites and the equipment expense of the project (direct cost of excavator, loader and dump truck). As a result of seeking the solution using a Solver, an optimal value was produced from borrow pit 1, 4 and 5 among the total 5 candidates borrow pits. Thus, the spoil hauling result value was obtained and it proves that it is rational to move 122.8 m^3 of soil from C1 to F3 and move 22 m^3 of ripping rock from C7 to F5.

			F3	F5	F48	F53	F61	F84	F88	F95	F108
Soil	C1	Quantity(m³)	122,8	-	-	-	-	-	-	-	-
		Distance(km)	0,06	-	-	-	-	-	-	-	-
		Cost($)	65,1	-	-	-	-	-	-	-	-
Reaping	C1	Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Blasting	C1	Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Soil	C2	Quantity(m³)	1,639,0	-	-	-	-	-	-	-	-
		Distance(km)	0,18	-	-	-	-	-	-	-	-
		Cost($)	869,0	-	-	-	-	-	-	-	-
Reaping	C2	Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Blasting	C2	Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Soil	C4	Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Reaping	C4	Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Blasting	C4	Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Soil	C6	Quantity(m³)	-	1,219,0	-	-	-	-	-	-	-
		Distance(km)	-	0,24	-	-	-	-	-	-	-
		Cost($)	-	646,0	-	-	-	-	-	-	-
Reaping	C6	Quantity(m³)	-	313,0	-	-	-	-	-	-	-
		Distance(km)	-	0,24	-	-	-	-	-	-	-
		Cost($)	-	207,0	-	-	-	-	-	-	-
Blasting	C6	Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Soil	C7	Quantity(m³)	-	37,0	-	-	-	-	-	-	-
		Distance(km)	-	0,30	-	-	-	-	-	-	-
		Cost($)	-	22,0	-	-	-	-	-	-	-
Reaping	C7	Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Blasting	C7	Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Borrow Pit1		Quantity(m³)	-	14,869,0	-	-	-	-	-	-	10,033,0
		Distance(km)	-	7,37	-	-	-	-	-	-	8,73
		Cost($)	-	247,362,0	-	-	-	-	-	-	166,910,0
Borrow Pit2		Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Borrow Pit3		Quantity(m³)	-	-	-	-	-	-	-	-	-
		Distance(km)	-	-	-	-	-	-	-	-	-
		Cost($)	-	-	-	-	-	-	-	-	-
Borrow Pit4		Quantity(m³)	-	-	-	18,466,0	-	-	-	-	-
		Distance(km)	-	-	-	6,83	-	-	-	-	-
		Cost($)	-	-	-	307,202,0	-	-	-	-	-
Borrow Pit5		Quantity(m³)	5,979,0	6,891,0	4,659,0	-	-	-	-	72,469,0	-
		Distance(km)	14,11	14,23	17,47	-	-	-	-	21,19	-
		Cost($)	93,488,0	107,748,0	72,848,0	-	-	-	-	1,133,133,0	-

From	To	Quantity(m³)		Distance(km)	Cost($)
C1	F3	Soil	122,8	0,12	65,1
C2	F3	Soil	1639,0	0,06	869,0
C4	F3	Soil	298,0	0,06	158,0
C6	F5	Soil	1219,0	0,24	646,0
C6	F5	Reaping	313,0	0,24	207,0
C7	F5	Soil	37,0	0,18	19,0
C7	F5	Reaping	22,0	0,18	15,0
Borrow Pit1	F5		14,869,0	7,33	247,362,0
Borrow Pit4	F53		18,466,0	6,81	307,202,0
Borrow Pit5	F5		5,979,0	14,15	93,488,0

Figure 15. Optimized result value of case study 2.

Figure 16 shows the optimal solution of Alt 1, 2 & 3 as previously introduced in Section 3.3 (direct hauling cost). Comparisons of direct hauling costs estimated from the transportation model theory (hauling distance x minimum volume) with direct cost from the model developed in this project were made. The results from the comparison show that there was a 5% decrease in the average reduction rates. Alt 3 among 3 alternatives was found to be most economical in establishing the hauling plan. Thus, it is necessary to perform earthwork according to an optimization result with Alt 3 (STA. 0 + 000–STA. 0 + 040, STA. 0 + 040–STA. 0 + 100, see Section 3.3).

	Direct hauling cost($) of transportation model (hauling volume x minimum value of hauling distance)	Direct hauling cost($) of earthwork volume optimization model	+/-(%)
Alt 1. Optimum solution	2,279,101	2,167,410	-5.01%
Alt 2. Optimum solution	2,283,212	2,171,526	-4.90%
Alt 3. Optimum solution	2,273,331	2,161,649	-4.92%

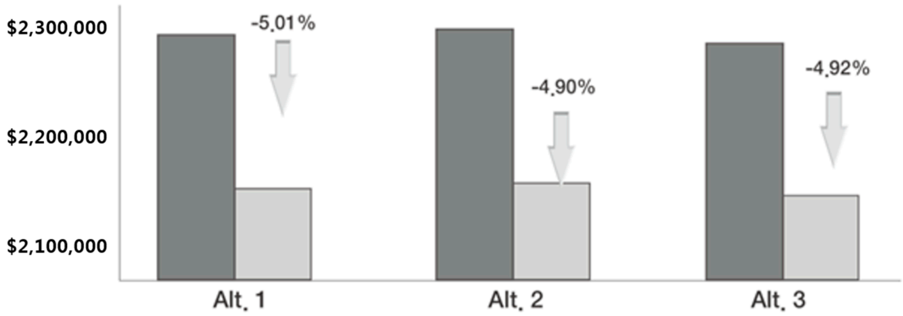


Figure 16. Comparison of result values for Case Study 2.

5. Conclusions

This study is intended to develop the prototype model which allows for the selection of a dump site/borrow pit as well as establish the most cost efficient spoil hauling plan. To that end, the study is conducted based on a transshipment transportation theory, equipment productivity, earthwork equipment cost, hauling distance, dump site/borrow pit data, referring to existing transportation model theory. Site conditions were incorporated in consideration of "internal hauling" and "external hauling" together. What is noteworthy is, the most cost efficient dump site/borrow pit can be selected in consideration of hauling outside the construction site to and from the dump site/borrow pit, instead of just hauling inside the construction site. The data on the productivity of equipment used for hauling and unit cost were based on a Design Guideline for National Road construction, Korea Price Information Gazette and Standard Estimate of Construction Work so as to enhance the reliability of the model.

The prototype model proposed is based on linear programming and was developed by collecting site conditions over entire sections through a hauling plan optimization algorithm. As a result of applying such site data to this model, the direct cost of earthwork including equipment expenses and the fees for a dump site/borrow pit was reduced compared to the method proposed in the preexisting transportation theory. In addition, the model further obtains the optimized transportation paths which may be valuable to reduce the occurrence of exhaust gas by earthwork equipment.

Should the model including indirect costs be developed in a way of incorporating with a time schedule through the algorithm and prototype model, it would be proven even more useful. In addition, should equipment productivity and equipment cost in other countries be incorporated, it would also be more practical for overseas projects in the future as the functional formula, objective function and constraint conditions developed could help develop a program which is optimized to different site conditions. In addition, the model will be more applicable on the earthwork sites if the model considers the tunnel and bridge constructions as well.

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