A STUDY ON SELECTING OPTIMAL HAUL ROUTES OF EARTHMOVING MACHINE

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ABSTRACT: Earthmoving equipment‘s haul-route has a great influence on the productivity of the earth work operation. Haul-route grade is a critical factor in selecting the haul-route. The route that has low grade resistance contributes to increase machine travel speed and production. This study presents a mathematical model called "Hauling-Unit Optimal Routes Selecting system" (HUORS). The system identifies optimal path that maximize the earth-work productivity. It consists of 3 modules, i.e., (1) Module 1 which inputs site characteristic data and computes site location and elevation using GIS(Geographical Information System); (2) Module 2 which calculates haul time; (3) Module 3 which displays an optimum haul-route by considering the haul-route's gradient resistances (i.e., from the departure to the destination) and hauling time. This paper presents the system prototype in detail. A case study is presented to demonstrate the system and verifies the validity of the model.

Keywords: haul-route; travel-time; grade resistance; rolling resistance; productivity; earthmoving operation; GIS

1. INTRODUCTION

To plan optimal equipment fleet combination, it is necessary to establish run-time of tasks consisting of earthmoving operation (loading, travel, dumping, and returning times, etc) and to seek for method to increase productivity of earthmoving model by reducing idle time of equipments. Calculating travel and returning times among run-time of each task has to plan haul-route of earthmoving equipments in advance unlike other times, i.e., loading and dumping times. Depending on which haul-route is selected, route's grade resistance, rolling resistance, and travel length would be different. It means that the choice of haul route influences on the calculation of travel time. Therefore, to plan haul-route reflecting reality faithfully, it is necessary to explore optimal route which contributes to productivity growth of earthmoving operation by considering gradient along with length of route [5]. Identifying optimal route is prerequisite that establish optimal equipment combination to assign to an earthmoving operation.

The paper presents a method that identifies an optimal haul-route of earthwork equipment and supports the decision-making on the optimal equipment combination to improve productivity of earthmoving operation. On selecting an optimal haul-route of earthmoving equipment between borrow pit and waste pit, travel time is calculated by considering all of grade resistance, rolling resistance, hauling distance, and equipment weight. This study develops mathematical model that establishes an optimal route by evaluating the fitness of haul-route.

2. LIETERATURE REVIEW

Many researchers studied how to manage economically large size earthmoving project which intensively uses high cost equipments. Existing researches includes FLSELETOR that selects an optimal earthmoving equipments combination by modeling uncertainty involved in earthmoving production cycle and that makes use of queuing and multi-dimensional objective functions(i.e. lowest cost, maximum productivity, minimum project period, etc)[6], a mathematical model that determines an effective haul-direction of remaining earth amount discharged from cutting section and imported earth amount for back filling[3], an optimal model of earthwork that uses genetic algorithm to select equipments combination, integrates GIS(Geographical Information System), and linear programming to determine "route-outside-site"[4], a model that selecting optimal loader-hauler combination by using genetic algorithm for construction equipment costs that includes equipment operating cost and equipment operator's wages. It investigates and solves production systems’ problems that determine earthmoving equipments combination by using existing queuing theory, simulation, linear program methodology [1], etc. In this sense, existing researches involved in earthmoving were mostly develops systems which implements methodological computation to determine earth work equipments combination or selecting earthmoving route for off job-site. However, they were designed to select optimal route without considering the height of haul-within-site.

To establish optimal combination of earth work equipments fleet, the plan of earthmoving equipments' haul-route should be calculated by computing the moving and returning tasks' time among the four tasks consisting of earthmoving operation. Since a selected haul-route gives great influence on equipment productivity, it needs careful plan. However, it is hard to establish suitable route because many variable factors are involved in productivity variation. Because the existing simulation models do not consider such variable factors causing productivity variation, it is noteworthy that the calculation of travel time affected to establish optimal earth work equipments combination.

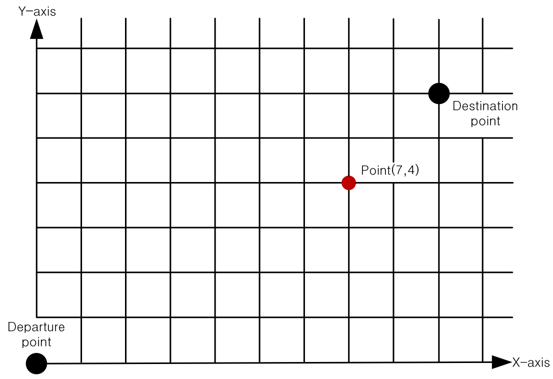

Figure 1. Dividing site in 2D grid

3. Haul-Unit Optimal Routes Selecting System

HUORS (Haul-Unit Optimal Routes Selecting system) supports hauling equipment route plan that should proceed to calculate the necessary time of travel and return tasks. It allows exploring proper haul-route by considering the productivity variation factors (type of ground, weight of hauling equipments, earth weight, haul amount, and type of tires) involved in earthmoving operation. The system consists of following three modules: 1) Module 1 -GIS information, 2) Module 2 - travel time Calculation, and 3) Module 3 - Optimal Route). The system algorithm is shown in Fig.2. The details steps of the algorithm are described as follows;

● Step1: Input values of the productivity variation factors relative to earthmoving operation. The vaules of productivity variation factors are attributes used in calculating grade resistance and rolling resistance obtained from input variables (type of ground, weight of hauling equipments, earth weight, haul amount, and type of tires). System defines X-Y coordinate corresponding to the point location by dividing site in 2 dimensional grid as shown in Fig 1 and assorts points intersecting X-Y axes to a point(I)(i.e., point marked at Fig 1 is intersecting point of X-axis 7 and Y-axis 4 and location is defined as (7, 4). Also system calculates X-axis distance ($X_{distance}$) and Y-axis distance ($Y_{distance}$) between two points by using user input information. X-Y coordinate(x_0, y_0) of departure point (N_0) is defined as (0, 0) and calculates X-Y coordinate(x_{n+1}, y_{n+1}) of destination point(N_{n+1}) with Eq.(3) and (4) by using user input coordinate space .

$$x_{n+1} = \frac{Xdistance}{I} \quad (3)$$

$$y_{n+1} = \frac{Ydistance}{I} \quad (4)$$

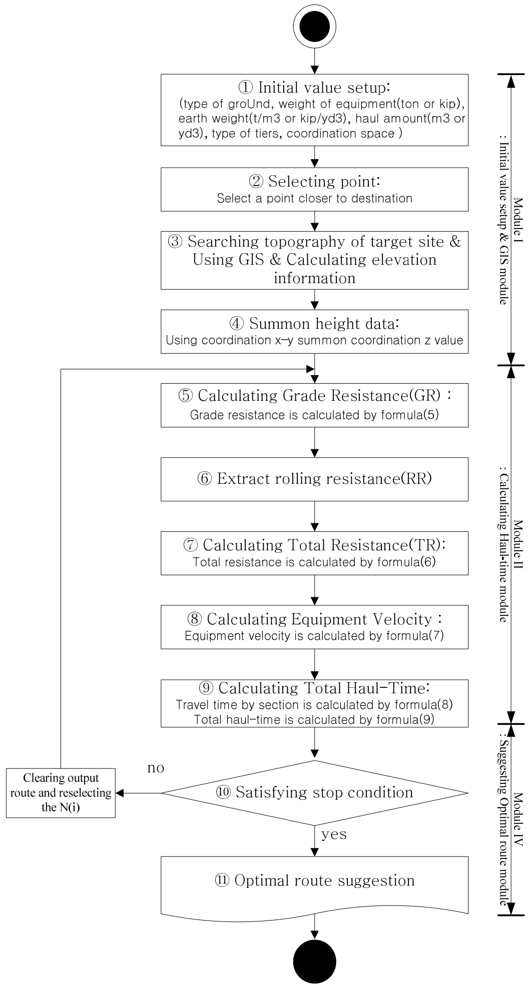

Figure 2. HUORS Algorithm

● Step2: Route of hauling equipment (P) is formed by connecting middle points existing between departure and destination (i.e., route is formed as departure(N_0) → point1(N_1) → point2(N_2) → · · · → pointN(N_n) → destination(N_{n+1})). Selecting middle points consisting of route is determined by location relation of preceding point and destination. Point after point(N_i) selects a point closer to destination than the pertinent point(N_i) as following point. Until destination is selected as final following point, the same method is repeated to form route. If Step1 sets up coordinate space narrow, space between points becomes close, it can draw more precise route. However, since it has to selects many points, route exploration time becomes longer. On the contrary, if the coordinate space is set up wide, space between points becomes farther so accuracy of route drops but exploration time becomes short. User needs to pay attention to set up coordinate space considering this fact.

● Step3: Select location of departure point and destination of route by searching topography of target site at Google Earth. To make flat rectangular coordinates system, departure point is defined as datum and X-Y rectangular coordinates were defined according to coordinate space(I) set up at Step1 by setting meridian passing through starting point on the flat as X-axis and south-north direction as Y-axis. Calculates elevation information (Z coordinate) corresponding to rectangular coordinate by using Google Earth providing elevation information according to longitude and latitude, then save them to spreadsheet.

● Step4: By tracing elevation information (Z coordinate) obtained at Step3 on every X-Y coordinate (x_i, y_i) of each point(N_i) of drawn hauling equipment route at Step2, summon height data by point(z_i).

● Step5: Following point (N_{i+1}) nearby specific point (N_i) is boundary point of a section. Difference of altitude across each section ($S_{i,i+1}$=N_iN_{i+1}) occurs grade resistance($GR_{i,i+1}$:%). The grade resistance is calculated by Eq.(5) using X-Y-Z coordinates of two points[5].

$$GR_{i,i+1} = \frac{(zi-zi+1)\times 100}{\sqrt{(xi-xi+1)^2+(yi-yi+1)^2}} \tag{5}$$

● Step6: According to conditions such as type of tires of hauling equipment input at Step1(i.e., Steel tires, Crawler type, Rubber type, etc), ground status of route(i.e., Smooth concrete, Good asphalt, etc), etc, extract rolling resistance value(ton) suggested by Robert. et.al(2009).

● Step7: Total resistance($T_{i,i+1}$:%) of route section($P_{i,i+1}$) is calculated by Eq.(6) by using grade resistance($GR_{i,i+1}$) calculated at Step5 and rolling resistance(RR) calculated at Step6 [5].

$$TR_{i,i+1} = GR_{i,i+1} + \frac{RR}{20} \tag{6}$$

● Step8: Hauling equipment velocity ($V_{i,i+1}$: km/hr) of route section($P_{i,i+1}$) is calculated by using Eq.(7) suggested by Haul-Unit Performance[2] using input variables input at Step1(hauling equipment weight, earth weight, haul amount, etc) and total resistance calculated at Step7.

$$V_{i,i+1} = K_0 \times [0.01 \times C_f \times (W_e + U_W \times B) \times TR_{i,i+1}]^n \tag{7}$$

Here, K_0: Coefficient of determination of regression analysis, C_f: Unit conversion coefficient, W_e: Hauling equipment weight(ton or kip), U_W: Earth weight of nature specimen(t/m^3 or kip/yd^3), B: Haul amount of hauling equipment(m^3 or yd^3), n: Index of determination of regression analysis. Weight of hauling equipment, earth weight of nature specimen state, and haul amount of hauling equipment use data input at Step1 and coefficient of determination of regression analysis, unit conversion coefficient, and index of determination of regression analysis refer to recommended value of Hicks(1993).

● Step9: travel time($T_{i,i+1}$: min) by route section($P_{i,i+1}$) is calculated by Eq.(8) using space coordinate of point and hauling equipment velocity calculated at Step10 (Robert, et.al 2009). Also, total travel-time of hauling equipment ($TotalT$: km/hr) is calculated by using Eq.(9) and used as objective function to evaluate haul-rout of equipment(P).

$$T_{i,i+1} = \frac{3.28\times\sqrt{(xi-xi+1)^2+(yi-yi+1)^2+(zi-zi+1)^2}}{0.62\times 88\times Vi,i+1} \times 60 \tag{8}$$

$$TotalT = \sum_{i=0}^{n} T^{i,i+1} \tag{9}$$

● Step10: Since different equipments are input to four tasks consisting of earthmoving operation, it cannot conclude route of minimizing travel-time as optimal route. Hence, use inputs optimum travel-time and evaluate total travel-time($TotalT$: km/hr) drawn at Step9 is corresponding to optimum travel-time range. Until route corresponding to optimum travel-time range is drawn, return to Step2 and repeat route exploration course and when optimum route is drawn, conduct Step11.

● Step11: Suggest total travel-time ($TotalT$: km/hr) of hauling equipment route satisfying stop condition of Step10 and route connecting points (i.e., starting point(N_0) → point1(N_1) → point2(N_2) → ··· → point N(N_n) → destination point(N_{n+1})) as graph.

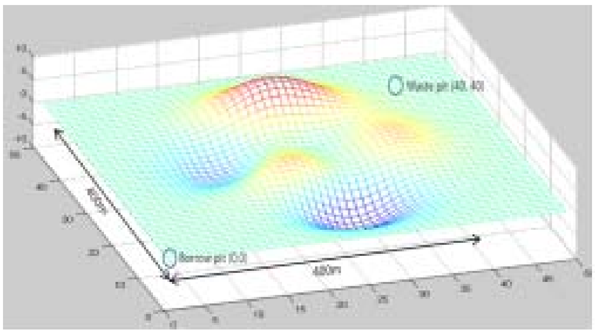

Figure 3. Dividing site in 2D grid

4. CASE STYDY

4.1 The Field outline

Prototype of HUORS which explores an optimal haul-route is developed as spreadsheet program. Using topographic map presented in Fig 3, practical applicability is verified. Whether the system draws optimal route of borrow pit and waste pit is verified. Waste pit is located 400m on X-axis from borrow pit and 400m on Y-axis.

4.2 Initialization

As shown in Fig 4, the system inputs 5 attribute values(type of ground, weight of hauling equipment, earth weight, haul amount, type of tires) that are productivity variation factors of earthmoving operation. It inputs X and Y axes distance(400m) of borrow pit and waste pit and inputs coordinate space(*I*) by considering accuracy of route and exploring time(i.e., 10m). X-Y axes coordinates((0, 0), (40, 40)) of borrow pit and waste pit of route is calculated by using Eq.2 and 3. Rolling resistance by selected ground and type of tires uses rolling resistance value by 7 states of ground and types of tires suggested by Robert, et.al 2009 with query. Ground state of case study assumes situation of "Earth, poorly maintained" and type of tire of hauling equipment assumes to use rubber tiers. Also information of equipment function, that is, equipment weight(ton or kip), earth weight of nature specimen(t/m^3 or kip/yd^3), haul amount of hauling equipment (m^3 or yd^3), etc are used in calculating equipment haul velocity at Step8. The case study assumes equipment weight 67.195 kips, haul amount of hauling equipment 15 yd^3, and earth weight of nature specimen 3.2 kips/yd^3 and conducts analysis.

Initial value setup			
from departure to destination X-axis distance(m)		400	
from departure to destination Y-axis distance(m)		400	
coordinate space(m)		10	
	coordinate X	coordinate Y	coordinate Z
Departure point	0	0	0
Destination point	40	40	0.132849228
Type of surface		Loose sand and gravel	
Empty weight of haul unit(ton or kip)		67.195	
Bank unit weight of material(ton/m3 or kip/yd3)		3.2	
Bank carrying capacity of haul unit(m3 or yd3)		15	
Type of tier		Rubber tire	

Figure 4. Initial value input tap

4.3 Optimal route suggestion

User sets up optimum travel-time range at Step10 that is evaluation step of suitability of route. Range setup is set up by considering operating time and idle time occurring by cooperation between each assigned equipment to 4 tasks consisting of earthmoving operation. Until drawing route satisfying range of travel-time designated as objective function, Step2 through Step9 are repeated and re-evaluation is conducted at Step10. Through such suitability evaluation, haul-route judged to be reasonable by satisfying optimum travel-time is output like Fig 5. That is, route suggested by considering variable factors of productivity(i.e., on-site ground state, tire type of hauling equipment, distance by section and height difference, equipment weight, haul amount of equipment, earth weight) input at Step1(step of initial value input) is evaluated at Step10 and travel-route satisfying travel-time range set up at beginning is drawn.

5. Conclusion and contributions

The study achieves following contributions. First is to suggest route exploration algorithm considering productivity variation factors (ground type, hauling equipment weight, earth weight, haul amount, type of tire). Second is to suggest method of exploring case to construct a new route(that is, travel-route of hauling equipment within site), not a method of selecting route by evaluating already existing route (route built for car movement) for earthmoving. Third is to suggest methodology of drawing haul-route with haul time of optimum range by fulfilling system verification using case topographic map set up arbitrarily to verify practical applicability of HUORS(Haul-Unit Optimal Routes Selecting system).

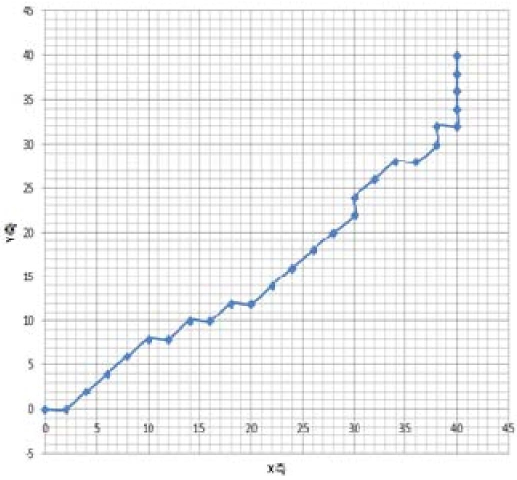

Figure 5. Presenting optimal route

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