Collaborative Optimization of Earthwork Allocation and Dynamic Opening of the Disposal Sites of the Canal Project

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Abstract. In the construction of a canal project, how to deal with a huge amount of earthwork is an urgent problem, except for the part of filling areas, the surplus earthwork should be placed at the disposal sites. To minimize the total cost of the project and to protect the environment as much as possible, the dynamic opening of disposal sites should be considered jointly with the earthwork allocation. A MILP model is proposed to solve the problem of collaborative optimization of earthwork allocation and dynamic opening of the disposal sites and a case is used to verify the model is economical, scientific, and reasonable.

Keywords: earthwork allocation; disposal sites; canal project; dynamic programming; mixed-integer linear programming

1 Introduction

The canal project can facilitate trans-regional transportation and bring great economies of scale, but the amount of earthwork excavated by the canal project is very large, so how to deal with the huge amount of earthwork is an urgent problem. Most previous literature considers the earthwork allocation problem as a linear programming model [1-6], in which the opening of disposal sites is fixed throughout the construction period. However, it is optional to choose which disposal sites should be used in the project and when the disposal sites are open. To minimize the total cost of the project and to protect the environment as much as possible, the dynamic opening of disposal sites should be considered jointly with the earthwork allocation [7]. Except for the basic allocation cost of earthwork, some literature considers multiple objectives, including the minimum risk, optimal material quality, and minimum environmental impact [8-9], or the intensity of road transportation [10-11]. In addition, some researchers transform the problem of earthwork allocation into VRP (vehicle routing problem) [12], or add uncertainty into the model [13]. This paper establishes the mixed integer linear programming model of the collaborative optimization of earthwork allocation and dynamic opening of the disposal sites based on the basic characteristics of earthwork allocation, and considering multiple objectives including earthwork allocation cost, disposal sites opening cost, and

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environment protecting cost and solve it by Gurobi. Finally, a case study is used to verify the economy, scientificity, and rationality of the model.

2 Problem Statement

The amount of earthwork in the canal project is very huge, so how to handle the excavated earthwork has become a crucial problem. The destination of excavated earthwork can be divided into two types: filling and disposal. There are filling areas that have demand for certain types of earthwork, however, as the amount of excavated earthwork is too large, the remaining earthwork is still enormous and it should be placed at disposal sites.

Each disposal site q has an activating cost γ_q, which means if this disposal site is used in the project, there is a cost; on the other hand, when the disposal site is open and earthwork is placed in it, there is another environmental cost β_q because the earthwork would cause the erosion of soil, and we want to minimize this cost to protect the environment.

The capacity of each disposal site is V_q, the capacity difference between different disposal sites can be large, and the nearest disposal site of some excavation area may not be able to store all the surplus earthwork of this excavation area, so it is necessary to transport the earthwork to other disposal sites for storage.

Since the transportation of earthwork is a long-term process and the opening of the disposal sites requires costs, the disposal sites do not need to be open throughout the whole construction process to minimize costs. Therefore, dynamic opening of disposal sites can greatly reduce the total cost (see Fig. 1).

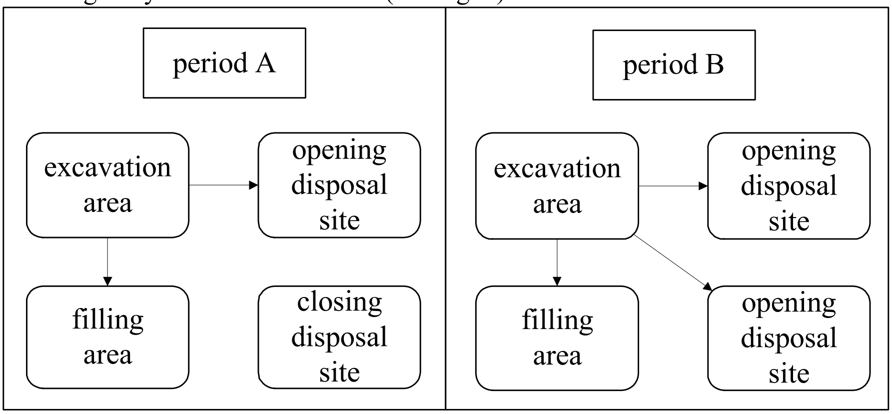

Fig. 1. Dynamic disposal sites opening and closing illustration.

3 Mathematical Model

3.1 Model Assumptions

According to the background requirements of the problem and the rationality and effectiveness of the model, the following assumptions are made during the modeling.

- The total amount of excavation of the project is extra-large and is greater than the total amount of filling demand so the disposal sites are necessary while the borrow area is not needed;
- The mined earthwork has been converted into a loose square, that is, the natural square has been loosened by artificial or mechanical excavation;
- Each disposal site can be opened only if it is activated beforehand, that is, only disposal sites that have been determined to be put into use before construction can be opened during the construction period.

3.2 Symbols

Set the excavation area as $i \in I$, the filling area as $p \in P$, the optional disposal sites as $q \in Q$, and the receiving area set (equivalent to the union of filling area and optional disposal sites) as $J = P \cup Q$, which is the destination of the excavated earthwork. Set the construction period as $t \in T$, material type as $k \in K$, the total amount of material k excavated in excavation area i as O_{ik}, the demand of material k in filling area p as D_{pk}, and the capacity of disposal site q as V_q. The decision variables of the model are as follows:

x_{ijkt} represents the transport volume of the k material from excavation area i to receiving area j in period t, which is a non-negative continuous variable.

y_{qt} indicates whether the disposal site q is open during period t, which is a binary variable.

z_q indicates whether the disposal site q is activated during the entire construction period, which is a binary variable.

Set the transportation distance from excavation area i to receiving area j as d_{ij}, and the cost of transporting one kilometer of one unit of earthwork is α. The environmental protection cost, i.e., unit time opening cost of the disposal site q is β_q and the activating cost is γ_q.

3.3 Objective Function

$$
\begin{aligned}
& min\, F = F_1 + F_2 + F_3 \\
& = \alpha \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} \sum_{t \in T} d_{ij} \cdot x_{ijkt} + \sum_{q \in Q} \sum_{t \in T} \beta_q \cdot y_{qt} + \sum_{q \in Q} \gamma_q \cdot z_q
\end{aligned} \tag{1}
$$

Formula (1) is the objective function of the model, which minimizes the total cost, including transportation cost F_1, environmental protection cost F_2, and disposal site activating cost F_3.

3.4 Constraints

$$\sum_{j \in J} \sum_{t \in T} x_{ijkt} = O_{ik}, \forall i \in I, k \in K \tag{2}$$

$$\sum_{i \in I} \sum_{t \in T} x_{ipkt} = D_{pk}, \forall p \in P, k \in K \tag{3}$$

$$\sum_{i \in I} \sum_{k \in K} \sum_{t \in T} x_{iqkt} \leq V_q, \forall q \in Q \tag{4}$$

$$\sum_{i \in I} \sum_{k \in K} x_{iqkt} \leq V_q \cdot y_{qt}, \forall q \in Q, t \in T \tag{5}$$

$$\sum_{t \in T} y_{qt} \leq |T| \cdot z_q, \forall q \in Q \tag{6}$$

$$\sum_{k \in K} x_{ijkt} \leq R_{max}, \forall i \in I, j \in J, t \in T \tag{7}$$

$$x_{ijkt} \geq 0, \forall i \in I, j \in J, k \in K, t \in T \tag{8}$$

$$y_{qt} \in \{0,1\}, \forall q \in Q, t \in T \tag{9}$$

$$z_q \in \{0,1\}, \forall q \in Q \tag{10}$$

To achieve the expected effect of the major project, it is necessary to excavate and fill the earthwork, and it is required to meet the excavation schedule of the project. Formula (2) is the constraint of excavation quantity, which means the total excavated earthwork of excavation area i should be equal as the predetermined excavation demand; Formula (3) is the constraint of filling quantity, which means the total filling earthwork of filling area j should be equal as the predetermined filling demand; Formula (4) is the capacity constraint of the disposal sites site, the quantity of earthwork stored in the disposal sites site must not be greater than the its maximum storage capacity; Formula (5) is the opening constraint of the disposal sites, and only when the disposal site is open can the earthwork be stored; Formula (6) is a constraint on the availability of disposal sites, and only the disposal sites selected to be activate in advance can be opened; Formula (7) limits the maximum road transport intensity in each period, where $R_{\max}$ represents for the maximum road transport intensity; Formulas (8) - (10) are variable constraints, which specifies that **x** is non-negative continuous variable while **y** and **z** are binary variables.

4 Numerical Experiments

The proposed canal project is an artificial project. Based on the problem background of the utilization of huge amounts of earthwork in major excavation projects, it is assumed that there are currently 3 excavation areas, numbered D1, D2, and D3; 2 filling areas, numbered F1 and F2; 4 disposal sites, numbered T1, T2, T3, T4; two types of earthworks are produced, respectively, A and B. The amount of type A earthwork produced by the three excavation areas is 11, 16, and 19 units respectively, where the unit of earthwork is 10^4m^3, and the amount of type B earthwork produced is 18, 13, and 14 respectively. The demand for type A earthwork in the two filling areas is 15 and 13 respectively, and the demand for type B earthwork is 18 and 10 respectively. The demand for the filling area is determined. Disposal sites T1, T2, T3, and T4 can each accept 20, 10, 15, and 5 units of earthwork. The unit storage cost of disposal sites per unit period of operation is 20, and the cost per unit distance of earthwork transportation is 1. Table 1 shows the basic information of the case.

Table 1. Location and demand information of the project.

name	area type	demand	capacity	longitude	latitude	activating cost	environmental protection cost
D1	excavation area	11;18	0	109.6	22.1	0	0
D2	excavation area	16;13	0	110.1	22	0	0
D3	excavation area	19;14	0	110.5	21.9	0	0
F1	filling area	15;18	0	109.9	22.3	0	0
F2	filling area	13;10	0	109.8	21.5	0	0
T1	disposal site	0	20	109.4	22.4	2000	200
T2	disposal site	0	10	110.3	22.4	400	200
T3	disposal site	0	15	109.5	21.7	1000	200
T4	disposal site	0	5	110.3	21.6	200	200

In Table 2, the second row shows the dynamic opening of disposal sites. Take period t=0 for example, T1 and T2 disposal sites are open while T3 and T4 are closed, $2.75\times10^4\,m^3$ material of type A and $2.25\times10^4\,m^3$ material of type B will be excavated from D2 and fill F1, $2.25\times10^4\,m^3$ material of type B will be excavated from D1 and fill F1, $5\times10^4\,m^3$ material of type A will be excavated from D2 and be disposed in T1, and the situation is similar in other periods.

Table 2. Summary results of opening disposal sites and transportation amount.

		t=0	t=1	t=2	t=3
opening disposal sites		T1; T2	T1	T1; T4	T1
from	to	transportation amount ($A/10^4m^3$; $B/10^4m^3$)			
D1	F1	0; 0	0; 2.25	0; 2.25	0; 2.25
D2	F1	2.75; 2.25	2.75; 2.25	2.75; 2.25	2.75; 2.25
D3	F1	1; 0	1; 4	1; 0	1; 0
D2	F2	0; 1	0; 1	0; 1	0; 1
D3	F2	3.25; 1.5	3.25; 1.5	3.25;1.5	3.25; 1.5

D1	T1	5; 0	1; 4	0; 5	5; 0
D2	T2	5; 0	0; 0	0; 0	0; 0
D3	T2	0; 5	0; 0	0; 0	0; 0
D3	T4	0; 0	0; 0	2; 3	0; 0

In Fig 2, the square marker represents the filling area, the circular marker represents the excavation area, the upper triangle marker represents the closing disposal sites, and the lower triangle marker represents the opening disposal sites. The text in the upper right corner of the excavation area indicates the amount of each material that has been excavated and the total demand that needs to be excavated, namely O_{ik}. The text in the upper right corner of the filling area indicates the amount of each material that has been filled and the total demand that needs to be filled, namely D_{jk}. The text in the upper right corner of the disposal sites indicates the amount of material that has been deposited and the maximum amount that can be deposited, that is, the capacity V_q. The four plots represent the deployment at t = 0, 1, 2, and 3. A and B stand for the type of material.

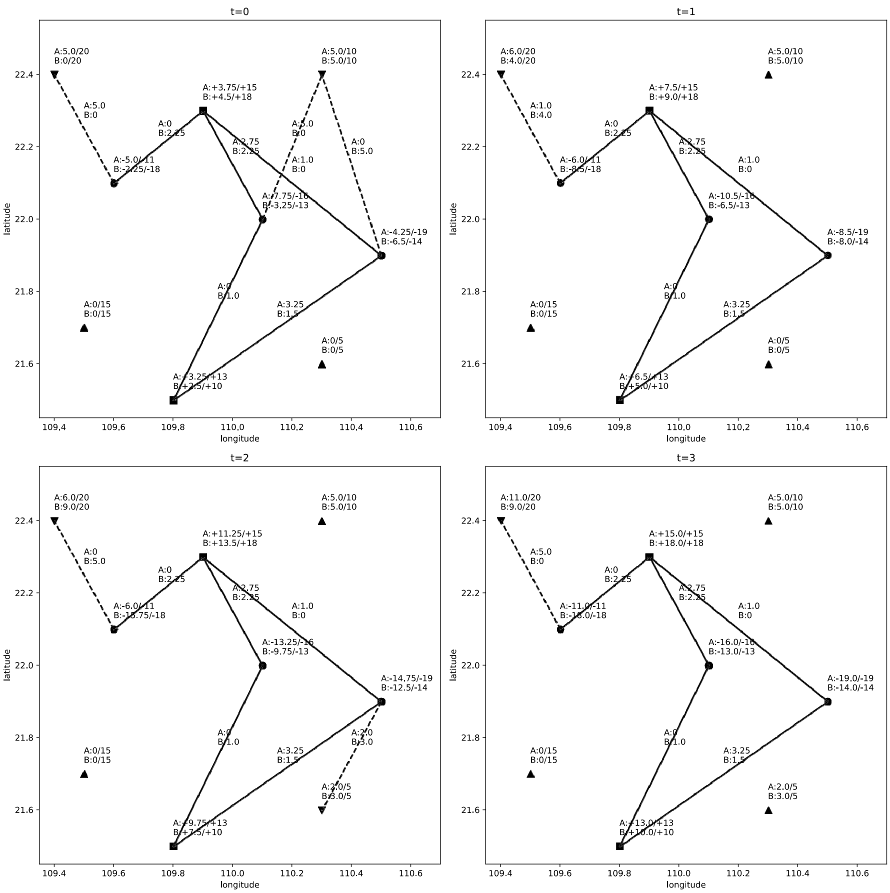

Fig. 2. Results on all periods.

5 Discussion and Conclusions

The above research shows that the proposed model can be used to characterize the canal project earthwork allocation and disposal site opening scheme. It can be seen from the result that the transportation scheme is balanced and the dynamic opening of disposal sites can reduce the cost, the dynamic opening of the disposal sites has achieved the expected effect. The disposal sites are gradually opened over time to absorb the excess earthwork so that the earthwork can be completely treated at the cost of minimizing the cost to meet the needs of excavation and fill.

References

1. Wang X.X., Application of optimal allocation Model in earthwork excavation and fill engineering. Shanxi Water Resources, 2019. 35(9): 36-39. (in Chinese)
2. Yang K. and Lu W., Research on mathematical models in the allocation of earth and rock. Journal of Hebei Engineering Technical College, 2017(3): 64-66. (in Chinese)
3. Deng L.N. et al., Earthwork allocation based on linear programming mathematical model algorithm. Journal of Civil Engineering and Management, 2018.35(2): 25-31. (in Chinese)
4. Mohamad Karimi, S., et al., Fuzzy Optimization Model for Earthwork Allocations with Imprecise Parameters. Journal of construction project and management, 2007. 133(2): 181-190.
5. Liu G.X., et al., Study on mathematical model and scheme fineness of road earthwork allocation. Design of Hydropower Stations, 2022. 38(2): p. 66-69. (in Chinese)
6. Zhao Y. et al. Research on Earth and rock allocation of faced rockfill dam based on particle swarm optimization and genetic algorithm. Journal of North China University of Water Resources and Electric Power (Natural Science Edition), 2022. 43(2): 54-59,68. (in Chinese)
7. Li T.S. and Zhang J., Research on two-layer programming model and algorithm for soil and rock allocation problem. Journal of Railway Engineering, 2012(4): 108-112. (in Chinese)
8. Luo S.P. et al., multi-objective fuzzy optimization of the mining scheme of the stockyard. Journal of Wuhan University of Hydraulic Engineering and Electric Power. 2000. 33(6): 47-49. (in Chinese)
9. Qi F., Study on optimal allocation method of earth and rock for railway construction projects. Soil and Water Conservation in China, 2023(6): 36-39. (in Chinese)
10. Shen M.L. et al., Joint optimization model of rockfill dam earth and rock allocation and road transportation intensity. Journal of Wuhan University (Engineering Edition). 2006. 39(5): 14-18. (in Chinese)
11. Liu Z.X. et al. Study on multi-objective dynamic optimization model of rockfill dam material transfer. Water and Electricity Energy Science, 2004(02): 60-63. (in Chinese)
12. Zhang, Q., et al., Multi-depot Two-Echelon Vehicle Routing Problem for Earthwork Allocation Optimization. Mathematical problems in engineering, 2022: p. 1-14.
13. Katebi, A., et al., Towards Developing a Robust Optimization Model of Earthwork Al-locations in Roadway Projects. Iranian journal of science and technology. Transactions of civil engineering, 2023. 47(4): p. 2507-2520.