Research on Optimal Path Selection of Muck Truck Considering Time Cost and Safety Risk

Fangjian Shang1, Fujun Wang1, Xiaofeng Zhang1 and Jun Bi2

1 School of Traffic and Transportation, Beijing Jiaotong University, 100044, Beijing, China

2 Corresponding author’s e-mail: bilinghc@163.com

Abstract. The safety problem of muck trucks has attracted more and more attention. How to balance the economic benefit of transporters and the safety of muck trucks has become a urgent problem to be solved. In this paper, the two factors of the time cost of the muck truck and the safety risk during the transportation are considered comprehensively (in order to simplify the discussion, the situation of single starting point and single destination is considered), and the path of the muck truck is optimally selected. Taking the construction waste disposal sit of Qingcaigou in Xi'an as an example, the model is constructed and the Dijkstra algorithm is used to solve the problem.

1. Introduction

The muck truck play a huge role in the urban construction process, but at the same time, the safety problems brought by the muck truck are particularly prominent. Taking Shanghai as an example, in the first quarter of 2019, there were 528 traffic accidents of muck trucks, including 10 death traffic accidents which result in 10 deaths. The accident rate in Shanghai's muck transportation industry was 9.3 per 100. The death rate is 18 per 10,000, and the illegal rate is 1.5 per muck truck[1]. Behind the statistics are direct economic property losses and personal injuries. How to make the muck truck choose a relatively safe path is of great significance for reducing the number of muck accidents and ensuring the safety of people's lives and property. However, we can not give up eating for fear of choking, completely disregarding the economic interest of transporters or transport companies. How to rationally choose the path to balance protecting the lives and property of the people and not damaging the the economic interest of the transport enterprises too much has become an urgent problem to be solved.

In the past, most of the researches considered transportation safety or economic benefit (time cost) separately. Wei Luo, Xiaorong Zhang and others have improved the Dijkstra algorithm and applied it to the optimization of medical logistics distribution network [2]. Wenyun Tang, Jianxiao Ma and zhen Yang proposed an offline map matching algorithm based on multi-path traffic network, and compared its accuracy with the accuracy of the shortest path algorithm [3]. Xiaohang Pan of Xi'an Technological University considered the safety risk of the muck truck and the economic interests of the transporter. The optimal path of the muck truck was modeled with a double objective function and solved [4]. Zeng,W and Church,RL improved the effect of Dijkstra algorithm by using network attributes related to GIS source data [5]. Based on the trajectory data of muck trucks, Peijun Guo, Chunling Hu and other people constructed a path evaluation model for muck trucks, which provided a basis for path gauge selection. [6]. Based on the trajectory data of muck trucks, Li Zhu constructed the muck vehicle path evaluation model from various aspects, and studied the transportation path planning
problem of muck trucks [7]. The road transport vehicle dynamic information application technology service platform in Shandong Province can monitor the details of all networked vehicles in real time, including location, speed, continuous driving time and other information, which can reduce the safety risk of muck trucks to some extent [8].

Regarding the problem of vehicle routing, the existing theories have studied the path of time cost or safety risk separately. There is a lack of researches on muck trucks considering the time cost and safety risk comprehensively. In view of the shortcomings of previous researches, this paper comprehensively considers the time cost (economic benefit) and safety risk of muck trucks and selects the optimal path. It is of great significance to ensure the economic benefit of the muck truck, to reduce the number of accidents of the muck trucks and to improve the safety factor of the surrounding roads.

2. Establishment and solution of optimal safety path model for muck truck

2.1. Problem description and modeling

In order to distinguish the safety risk of the muck truck and the safety risks of other vehicles, and facilitate the description of the problem and the construct the model, the road safety risk and the path safety risk of the muck are defined here.

Definition 2.1 Road section safety risk: The probability of an accident when the muck truck passes this section.

Definition 2.2 Path safety risk: The probability of an accident occurring when a muck truck passes this route.

2.1.1. Problem description

If we only consider the economic benefit of the muck trucks, some muck truck transport companies now charge a fee according to the length of the path, that is, a certain fee per kilometer, and some muck truck transport companies adopt a packet-dry charging method, that is, regardless of how long it takes for the muck transport company to transport a certain amount of construction waste or other items, the cost is the same. No matter what kind of charging method is adopted, the faster the muck truck is, the more economic benefit will be obtained per unit time. Therefore, considering the economic benefit of the muck truck alone is equivalent to the shortest path in the time dimension, so that the muck truck takes the shortest time to travel on the selected path.

If you only consider the safety risk of the muck, you are looking for the “shortest path” with the least safety risk. The muck truck has the least safety risk when driving on the “shortest path”.

This paper comprehensively considers the economic benefit of the muck transport company and the safety risk of the muck truck, and establishes a single objective function model to find the optimal path with low safety risk and small time cost from the construction waste generation source (departure) to the disposal site (destination).

2.1.2. Model

First, the roads in the actual problem are abstracted into an weighted network, that is, abstracted into an undirected graph G=(V, E, W, R). V represents the set of vertices in the graph, and E represents the set of edges with weights in the graph. W represents the set of time cost per side (can be expressed in terms of distance or time), and R represents the set of security risk for each side. Every vertex vi ∈ V(i=1,2,3,...,t), every arc eij=(vi,vj) ∈ E, the time cost corresponding to every arc w(eij)=wij ∈ W, the security risk corresponding to every arc s(eij)=sij ∈ S, source of construction waste, that is, the starting point of the muck is recorded as v1, and the disposal site of the construction waste, that is, the destination of the muck is recorded as vt.

Objective function:  \[ \min Z = \sum_{ij} x_{ij} * w_{ij} + k * \sum_{ij} x_{ij} * s_{ij} \]  \[ \text{S.t.} \quad x_{ij} = \{0,1\} \]
\[
x_{ij} = 1, \sum_{j=1}^{n} = 1. \tag{3}
\]

\[
x_{ii} = 1, \sum_{i=1}^{m} = 1. \tag{4}
\]

\[
\sum_{j} x_{ij} w_{ij} \leq W_h \tag{5}
\]

\[
\sum_{j} x_{ij} r_{ij} \leq S_h \tag{6}
\]

Among them, the objective function (1) represents the objective function that comprehensively considers the time cost and the security risk, and k, a constant, is the balance coefficient of the time cost and the security risk. The front half of the equation indicates that the time cost of the selected path of the muck truck is as small as possible, and the latter half indicates that the safety risk of the selected path of the muck truck is as low as possible. In the formula (2), \(x_{ij}\) represents whether the muck passes the section, and 0 means that the muck does not pass the section, and 1 represents the muck passing through the section. Equation (3) indicates that the muck truck is starting from the starting point and only one section connected to the starting point is selected. The formula (4) indicates that the muck truck reaches the destination from other vertex, and there is only one "other vertex". In the formula (5), \(W_h\) is the upper limit of the time cost of the path selected by the muck truck. In equation (6), \(S_h\) is the upper limit of the safety risk of the path selected by the muck truck[9].

2.2. Solving model

Step 1: Calculate the “weight” of the time cost and safety risk of each road section in the network. That is to say, the product of the safety risk and coefficient of the road section and the time cost are added as the “weight” of the road section. The set of “weight” is represented by \(Q\), and the "weight" of each road section \(q_{ij} \in Q\)

\[
q_{ij} = w_{ij} + k\cdot s_{ij}. \tag{11}
\]

Step 2: Using the Dijkstra algorithm, find the path that minimizes the "weight" from the starting point \(v_1\) to the ending point \(v_t\). Dijkstra algorithm steps: Use "()" to label permanent points and "[]" to mark temporary points. Regardless of the point marked by "()" or "[]", the first value in parentheses indicates the permanent labels connected to this point which makes the "weight" smallest from the start point \(v_1\) to this point, and the latter value represents the minimum "weight" from \(v_1\) to this point.

1. Starting from point \(v_1\), mark "[v_1, 0]" at point \(v_1\).
2. Finding the points directly connected to the permanent points, first mark them all with "()", and then pick out the point \(v_1\) to the point where the "weight" is the smallest among them, label it with "[]".
3. Repeat step (2) until all points are marked as permanent label points.

3. Xi'an Qingcaigou Construction Waste Disposal Site

Take the path selection of Xi'an muck truck as an example. Figure 1 is a map of the location of the construction waste disposal site of Qingcaigou in Xi'an and the nearby roads. Now, there is some construction waste in the Bailuyuan Ski Resort that needs to be transported to the construction waste disposal site of Qingcaigou in Xi'an. For the convenience of analysing, it is simplified to Figure 2. To simplify the actual problem, constraints (5) and (6) are ignored in this case.
Table 1. Time Costs and Road Safety Risks of Road Segments (vi, vj)

| V1   | V2   | V3   | V4   | V5   | V6   |
|------|------|------|------|------|------|
| (700, 0.1) | (800, 0.1) | (350, 0.1) | (300, 0.2) | (270, 0.2) | (450, 0.1) | (1000, 0.1) |

In the objective function, k is 100, then there is: min Z = Z1 + 1000*Z2.

Table 2. Integration of time cost and road segment safety risk of road segments (vi, vj)

| V1   | V2   | V3   | V4   | V5   | V6   |
|------|------|------|------|------|------|
| 800  | 900  | 450  | 500  | 470  | 1100 |
| 900  | 500  | 470  | 550  | 1100 |

The Dijkstra algorithm is used to solve the optimal path from V1 (White Luyuan Ski Resort) to V6 (Qingcaigou Construction Waste Disposal Field). Here we use the "labeling method", where "[]" is used to indicate permanent labels, and "()" is used to indicate temporary labels. The first round label: V1: [V1, 0]; the second round label: V1: [V1, 0], V2: [V1, 800], V3: (V1, 900); the third round: V1: [V1, 0], V2: [V1, 800], V3: [V1, 900], V4: (V2, 1300); fourth round label: V1: [V1, 0], V2: [V1, 800], V3: [V1, 900], V4: [V2, 1300], V5: (V3, 1370); fifth round label: V1: [V1, 0], V2: [V1, 800], V3: [V1, 900], V4: [V2, 1300], V5: [V3, 1370], V6: (V4, 2400); sixth round label: V1: [V1, 0], V2: [V1, 800], V3: [V1, 900], V4: [V2, 1300], V5: [V3, 1370], V6: [V4, 2400]. The process is represented by the diagram: Figure 3(a) to Figure 3(f).

Using the backtracking method, the optimal path is: V1 → V2 → V4 → V6.
4. Conclusion
This paper comprehensively considering the time cost and transportation risk of the muck truck, establishes the model and uses the Dijkstra algorithm to calculate the shortest path, which is relatively intuitive and easy to understand. The result can provide basis for the muck truck transport enterprises and relevant departments. However, this paper studies the situation of single-departure and single-destination trucks, and cannot cover all the transportation situations of the muck trucks in reality. Therefore, it is necessary to further study the transportation situation such as multiple destinations at a single departure point, single destination at multiple departure points, and the like.

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