Estimation of Travel Times in the Context of Intermodal Transportation

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Abstract. Travel-time is recognized as a critical ingredient in assessing the service factor of transportation. Two approaches to estimation of travel time using geographical information systems (GIS) — raster calculator (Euclidean distance algorithm or cost distance algorithm) and network analysis — are described. After analyzing the travel-time components and tendency of modern transport systems, it is suggested that travel time for a specific journey is uncertainly and transportation changes the relationship between space and time with the emergence of intermodal transport. Focusing on the estimation of travel time in the context of intermodal transport, a hybrid model combining raster calculator and network analysis is proposed in this paper for calculating the travel times between origin point and the whole space. In this proposed model, the travel-time components may include an initial walk time from origin point to public transport stop, transport time between the same or different transportation network modes, and a final walk time from public transport stop to destination point. The uncertainly part in travel-time components, such as the time of travel (whether of departure or arrival), transport congestion, and the time for transmodes can be solved by network setting. This paper integrates the model into a GIS environment for regional planning, which successfully copes with the complexity of the public transport of a large region. Finally, this paper explains the result of different method.

Keywords: intermodal transportation, travel times, time geography, spatial structure

1. Introduction

Travel time is widely used in various practical applications. It is not only an important parameter for evaluating the performance efficiency of transportation system (Murray, 2003), but also very useful for the traveler. During the past decade considerable attention has been focused on the estimation of travel time by different technologies and methods (Lightfoot, 2007; Sullivan et al., 2000). Therefore, travel times can be obtained in a number of ways. The usual methods for travel time calculation, based in graph theory, are easy to assay in the shortest-path distance between two points, but if one wants to create a continuous model, we must work in a raster environment. This, of course, will reduce the accuracy of the information; however, it opens a wide range of new analysis capabilities (Julio, 1999).

An interesting issue for travel time estimation is about the choice of transportation modes. The faster the mode, the less the time that can be consumed within the same distance. The improvements in transport mode involve easier, faster and cheaper access between places, which is called as a space/time convergence. Meanwhile, space/time convergence can also be inverted under specific circumstances, which means that a process of space/time divergence takes place (Rodrigue et al., 2006). For instance, congestion is increasing in many metropolitan areas. Therefore, modern transport mode has both advantages and disadvantages for journey like every coin has two sides. In recent years, the intermodal transport becomes the most important transport mode than others (Rodrigue et al., 2006). The estimation of travel time in the intermodal transportation context includes several uncertain factors, such as choice of modes and route choice.
This paper focuses on the accurate estimation of the minimum travel times between pairs of points. The next section briefly describes the conceptual model and traditional calculation method for travel times in the intermodal transportation context and proposes an innovative approach to integrate a hybrid model in ArcGis environment using Python. Following this, a case study is given to illustrate the approach and related results are analyzed in section 3. Finally, the conclusions and future directions are provided.

2. Methodology

Travel time in the intermodal transport context is influenced by many variables. In general, these variables can be categorized into two groups: statistical factors and stochastic factors. Statistical factors describe the geographical characteristics of the areas, such as the distance between origin and destination points and transportation modes. Stochastic factors are characteristics of transport system and are, in contrast to statistical factors, individual and uncertain. These factors mainly include congestion, traveler behaviors, and waiting times. The ideal approach to estimation of travel time in the intermodal transportation context might involve creating a more complex time function based on all these factors (and others). However, this would involve many difficult processes and need detailed data for transport modes. Because of data limitations, methodological limitations or a combination of the two, the estimation for a specific journey would be a questionable procedure. Furthermore, the mean travel time is rather significant to assess the transportation systems at the national or regional scale than the individual. These considerations eliminate the need for sophisticated simulation of stochastic factors, and reduce the problem to estimation of travel time in the intermodal transportation context for the study area. In this section, it discusses the uncertain factors of calculation and gives an interface in the proposed model for the potential application.

2.1. Conceptual model

Travel time is the time it takes people to travel from one location to another in transportation system. According to the actual situation in the environment of intermodal transportation, the conceptual model of the total time from origin to destination includes three parts (Murray et al., 1998):

- Part (1) the time from origin to the point on the network;
- Part (2) the network time from the point near the origin to the point near the destination;
- Part (3) the time to the destination from the point on the network (similar to Part (1)).

If the origin and destination location are exactly on the network, the time of part (1) and (3) equals zero. If not, it should compare different station points and select the faster transport mode point. The detailed algorithm for comparing and selecting point will be presented in the following traditional methods and hybrid model sections and the conceptual model is shown as below.

![Diagram of Conceptual Model](image)

Fig. 1: Conceptual model for estimation of travel time.
2.2. Traditional methods
Many approaches have been proposed for travel time calculation both due to application needs and technological advances. In such studies, geographic information system (GIS) is generally used to estimate the travel time. With the development of GIS, most commercial GIS offer capabilities for carrying out travel time calculation and transportation analysis and the result is widely accepted (Liu and Zhu, 2004). The simplest approach may be by establishing a buffer around the origin point and interpolating the delay time in the buffers. This approach raises a complicating issue of the homogeneous space. In fact, the property of heterogeneous space is more common and some precise approaches describe it. According to the spatial data structure in GIS, these methods can be categorized into two groups: raster calculator and network analysis.

Raster calculator provides a kind of method to perform cell-based (raster) analysis. Cell-based systems divided the world into discrete uniform units called cells, based on a grid structure. Each cell represents a certain specified portion of the whole called resolution cell, such as square kilometer, hectare, or square meter. Cells are given values that correspond to the features or characteristics that are located at or describe the locations they represent, such as travel time for moving through cells. Travel time algorithm in raster system utilizes the node/link cell representation. In the node/link representation, each center of a cell is considered a node and each node is connected to its adjacent nodes by links. Travel time is calculated from the origin points to each of the surrounding cells. The shortest travel time to origin points is determined by the accumulated travel time and then this adjacent cell is activated as a part of origin points. Again, the travel time is calculated from the origin points including the activated cell to their surrounding cells and the next is chosen and the neighborhood is expanded. When all cells have been chosen, the result is the accumulative travel time raster.

As a continuous model, raster calculator provides a simple method to travel time estimation and is widely used in geography. Besides the travel time calculation, it is easy to extend some useful functions base on the raster environment, such as allocation analysis, direction analysis, and accessibility analysis. Because the raster calculator accumulates travel times from origin to the outer side, it is common that the outer is always larger than the inner. However, with the development of high-speed transport networks, it is reasonable that travel time of outer points with high-speed transition station would be shorter than the inner. Therefore, network analysis is proposed to solve these problems.

Network analysis is based on the graph theory and classical algorithm is Dijkstra’s shortest path algorithm and its modification. If the transport impedance changes from distance to time, the shortest travel time can be calculate in the transport network context. Network analysis absolutely follows the three parts in the conceptual model when calculating the travel time. Although the network analysis can explain the “skip” in travel time easily, it is difficult to calculate the travel time spent in part (1) or (3), especially when the point locates in the middle of line of networks. In order to solve this problem, a constant speed is often assigned to the gap among networks or lines and travel time is calculated by the distance between the origin/destination point and the station. It is not accurate because the gap space is also heterogeneous. Furthermore, the line of networks can not be partitioned off sometimes, such as airlines. An improved method would be to extend the raster calculator (or network analysis) for addressing these issues.

2.3. Hybrid model
The hybrid model simulates the process of journey according to the conceptual model. In the hybrid model, travel time of part (1) and part (3) can be calculated by raster calculator and part (3) can be estimated by network analysis. In the intermodal transportation context, route between origin and destination may be uncertain and how to choose the shortest travel time is the key problem.

In order to illustrate the route choice in the intermodal transportation context, this paper uses the following common notations:

- $O$: origin point
- $D$: destination point
- $T$: transition point
- $L_{OD}$: travel times from $O$ to $D$ in a lower speed transport mode
Figure 2 illustrates the route choice in the intermodal transportation context. In figure 2, these are three routes from $O$ to $D$, which are $L_{OD}$, $L_{OT} + H_{TD}$, and $L_{OT} + L_{TD}$. Obviously, Route $L_{OT} + L_{TD}$ would not be chose because of $L_{TD} > H_{TD}$. If $L_{OD} < L_{OT} + H_{TD}$, the route of $L_{OD}$ will be chose, and vice versa. So the condition of route choice is $L_{OD} - L_{OT} < H_{TD}$.

The following schema describes the data workflow that is used to obtain the optimal route shown above in the intermodal transportation context.

![Flow chart for route choice in the intermodal transportation context.](image)

**Fig. 2: Flow chart for route choice in the intermodal transportation context.**

![Data workflow for route choice in the intermodal transportation context.](image)

**Fig. 3: Data workflow for route choice in the intermodal transportation context.**

### 3. A case study

The public transport system in the study area will be the focus of the estimation of travel time presented in this paper. In this case, four modes of travel are available: walk, road, rail, and air. And the road networks can be grouped into 4 subclasses based on the average speed. Table 1 lists the category of public transport with average speed and Figure 4 presents the spatial distribution of it.
Table 1. Category of transport and its speed.

<table>
<thead>
<tr>
<th>Transport Category</th>
<th>Average Speed (Km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highway</td>
<td>80</td>
</tr>
<tr>
<td>National road</td>
<td>60</td>
</tr>
<tr>
<td>Provincial road</td>
<td>40</td>
</tr>
<tr>
<td>Municipal road</td>
<td>30</td>
</tr>
<tr>
<td>Ordinary road</td>
<td>20</td>
</tr>
<tr>
<td>Rail</td>
<td>50</td>
</tr>
<tr>
<td>Air</td>
<td>700</td>
</tr>
<tr>
<td>Walk</td>
<td>5</td>
</tr>
</tbody>
</table>

According to the hybrid model, estimation of travel time involves both raster calculator and networks analysis. A key issue is to identify different calculation methods for different transport modes. Because this paper works at a regional level and calculates the mean travel time for transportation system assessment, it is enough for our accuracy purposes — a cell with a pixel dimension of 100m. Using this pixel dimension and considering the property of transport mode, travel time estimation of walk, road and rail transport is implemented by raster calculator and air transport is simulated by network analysis.

To get the travel times from the whole study area to City A in the intermodal transportation context, travel time from the airport located in City A to other airports should be calculated in air networks and is assigned to city with the airport firstly. The second step is to estimate travel times from the study area to different airport respectively. These travel times in the second step should be modified by the value assigned to city, which means the improvement of transportation system by air networks. Finally, the travel time is identified by comparing value among the modified raster and choosing the minimum one of two cells.

In the second step, the key problem is to create a continuous cost surface in raster system. Two issues rise up. One is the gap between the edges of networks. To fill the gap, the average walking speed (5 Km/h) is assigned to every cell outside the networks. The other is the overlay of different transport modes in the same space. In order to minimize the travel time, it is common to choose the largest one.
Figure 5 presents travel times from the study area to the original City A by the method of raster calculator. Obviously, it is unreasonable that the travel time of City B with an airport is larger than some areas of its hinterland. In contrast, Figure 6 clearly shows the airport effect in travel time. That is why there is an island of travel time in the near areas of City A. That island corresponds to the surrounding of City B with an airport. It reflects the spatial structure of transportation system with the influence of high-speed transport modes.

4. Conclusions

Travel time is an important index for evaluating the performance efficiency of transportation system and useful information for the traveler. So it is widely used in various practical applications. This paper proposes a hybrid model for the estimation of travel time in the intermodal transportation context after analyzing and comparing two basic methods. Finally, a case study is given and the result is explained, which proved that the model proposed is valid.

The model presented here can receive several further developments. It can be improved by adding some uncertain factors, such as the punctuality and the frequency. Nevertheless, although this paper simplifies these uncertain factors in hybrid model, it is quite easy to extend the different application of this method presented here.

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6. References


