WebShipCost-An Intermodal Transportation Web-based Application

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Abstract

This paper enhances prior work on intermodal transportation by introducing a user-friendly, web-based application that determines the shortest time/cost intermodal routes for delivering goods from an origin to a destination. The overall research goal is to explore the advantages and disadvantages of barge transportation within an intermodal network. This paper discusses ongoing research in this area, system development, and a simple case study.

Keywords

Intermodal transportation, Shortest path, Web application

1 Introduction

An era of 'intermodalism' referring to interconnections among modes of transportation, use of multiple modes for a single trip, and coordinated transportation policy and decision making is emerging in this country [8]. In an intermodal transportation system, individual transportation modes are connected in a system that meets the needs of the shippers efficiently. Intermodal transportation systems attempt to lower transportation costs by allowing each mode to be used for the portion of the trip to which it is best suited.

Ongoing research has resulted in the development of WebShipCost, a WWW-based implementation of cost models that describe the costs incurred by three modes (rail, truck, and barge) within an intermodal transportation network. WebShipCost allows online determination of the minimum paths in terms of cost or time from an origin point to a destination point and enables shippers to understand the trade-offs associated with barge and container-on-barge transportation. WebShipCost consists of a database, the double-sweep algorithm for solving the *k*-shortest paths model, and a user interface. After user input of the origin, destination, shipment information, and objective (minimize total cost or total time of the shipment), the system displays the alternatives in order of increasing cost or time. The user can then compare the alternatives to the shipment's requirements, such as service level or commodity type, and choose the best-suited alternative. The user can also define additional networks to be analyzed by WebShipCost.

WebShipCost performs its analysis based on a formulation of the total transportation cost comprising of four elements: *travel cost*, *transfer cost*, *dray charges*, and *inventory carrying cost*. *Travel cost* is the cost to transport goods by the selected travel mode. The cost of transferring goods from one mode of travel at the load/unload site to another travel mode is the *transfer cost*. Transfer cost includes the cost of labor and equipment at any intermediate points where there is a change in travel mode. *Dray charges* are incurred for moving goods to/from a stationary site, such as a warehouse or factory from/to the loading site for transport. The fourth element of transportation cost is the in-transit *inventory carrying cost*. Inventory carrying cost is a function of the number of individual units being shipped and of the total transit time of a shipment. Typical carrying costs include storage space, insurance, taxes, loss due to spoilage or obsolescence, opportunity cost, etc.

2 Literature Review

The literature contains limited articles focused on intermodal shortest path identification. Grasman and Karunakara [3] formulate a multimodal logistic system to minimize cost within service time requirements. Their cost model includes transport cost of road, rail, sea, and air and transfer costs of ports and rail freight terminals. Dijkstra's algorithm is used to determine the optimal multimodal transportation network.

Tangential research in urban multimodal transportation networks provides additional insight into intermodal shortest path identification. Lozano and Storchi [5] utilize the Chronological Algorithm to solve the multimodal shortest viable path problem within an urban traffic situation. A multiobjective urban shortest path problem has been addressed through the development of a utility function model [7]. This model minimizes the overall cost, time, and user's discommodity.

Modal selection has been approached outside of the shortest path problem. McGinnis [6] provides an overview of four intermodal transportation models including Classical Economic Models, Inventory-Theoretic Models, Trade-Off Models, and Constrained Optimization Models. Classical Economic Models evaluate the fixed and variable costs of competing modes. Inventory-Theoretic Models seek to optimize modal choice by considering trade-off among rates, speed, dependability, and loss. The relevance of nontransportation cost differentials to shippers is evaluated in a Trade-Off Model. Constrained Optimization Models seeks to minimize transportation and nontransportation costs while adhering to product, distribution, and service constraints.

3 Application

3.1 Data Collection

Data collection for WebShipCost has taken place over several years [1, 10]. Currently the WebShipCost network consists of the following thirteen cities: Brownsville, Chicago, Cincinnati, Houston, Little Rock, Memphis, Mobile, New Orleans, Omaha, Pittsburgh, St. Louis, St. Paul, and Veracruz. The predominant data sources are the Arkansas Waterways Commission, Chew [2], Haulk [4], and Pittsburgh Waterways Commission. The following types of data were collected and archived in the WebShipCost database:

- Distance between cities in barge miles
- Distance between cities in rail miles
- Distance between cities in highway miles
- Inland barge transportation rate per container-mile
- Gulf coast barge transportation rate per container-mile
- Ocean going barge transportation rate per container-mile
- Rail transportation rate per container-mile
- Long haul truck transportation rate per container-mile
- Regional haul truck transportation rate per container-mile
- Local haul truck transportation rate per container-mile
- Truck-to-barge dray cost per shipment
- Truck-to-rail dray cost per shipment
- Barge transfer cost per container
- Rail transfer cost per container
- Truck transfer cost per container
- Barge transfer time in hours per container
- Rail transfer time in hours per container
- Truck transfer time in hours per container
- Inland barge average speed in miles per hour
- Gulf coast barge average speed in miles per hour
- Ocean going barge average speed in miles per hour
- Rail average speed in miles per hour
- Truck average speed in miles per hour

WebShipCost system users are permitted to override the database with their own cost and time data.

3.2 System Design

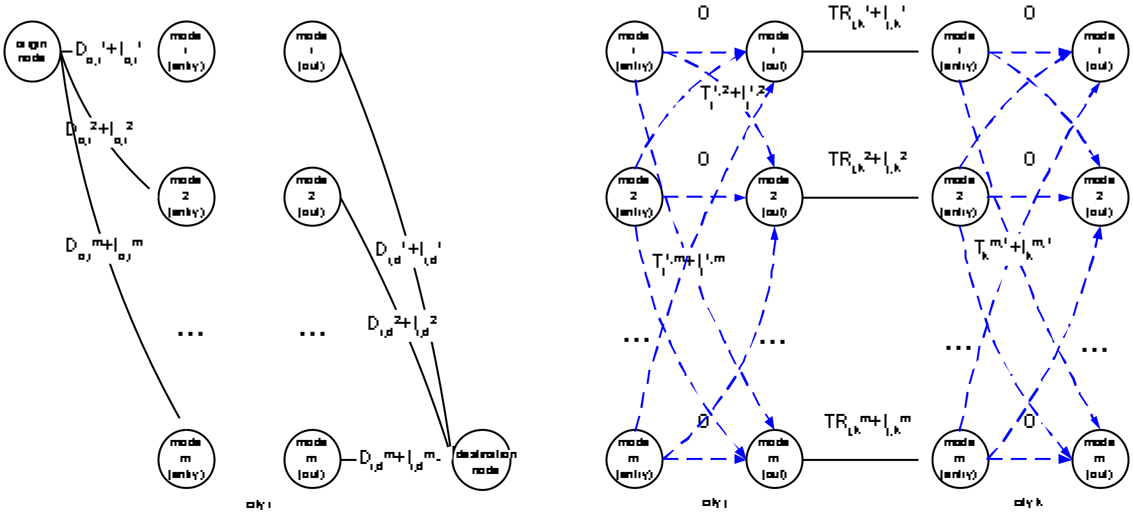
The conceptual data model that supports the WebShipCost application considers two key design criteria: flexibility for future extensions (sensitivity analysis, additional cost variation, etc.) and support for alternative algorithms. In order to achieve these two criteria, the model is a general object oriented transportation network model. The model includes general network elements including nodes and arcs. All costs incurred during the transportation were represented by classes or associations. The network is not dependant on a dedicated algorithm for computing the shortest paths. The time and cost information can be read from a database and thus be changed easily. Therefore, it is easy and convenient to perform sensitivity analysis and other parameter changes. From the conceptual data model, the database structure was designed and implemented. This procedure includes the implementation of object identity, the implementation of data domains and constraints, and finally the mapping of the relevant class diagrams to relational tables. The kth shortest path algorithm originally developed by Shier [9] was implemented within an object-oriented framework using Java. The algorithm takes a network object from the database along with the origin and destination and computes the kth shortest paths on the network. Finally, a standard Model, View, Controller (MVC) design pattern was used to build up the WebShipCost application where the algorithm and database interaction components, servlets and user-friendly Java Server Pages serve as the Model, View and Controller respectively.

3.3 Kth Shortest Path Problem

In the WebShipCost application, the kth shortest path algorithm was used to determine the optimal solution set instead of just finding the best solution. The general kth shortest path problem can be stated as follows: Given a finite directed network, $G = (N,A)$ a source node s and a destination node t, and a set of arc lengths c_{ij}, find the first, second,.., kth shortest paths from s to t, for any user-specified value of $k \in 1,2,\ldots$ In the intermodal transportation graph of WebShipCost, the arc lengths represent the time or cost associated with the corresponding transportation activities such as transfer, transport, etc. We will show the network presentation in the next section.

3.4 Mathematical Formulation

As previously stated, WebShipCost performs its analysis based on a formulation of the total transportation cost comprising of four elements: *travel cost*, *transfer cost*, *dray cost*, and *inventory carrying cost*. Figure 1 shows how each of these cost elements is represented in the network. We break each city into $2+2\times m$ nodes as showing on the left side of Figure 1, where m denotes the number of transport modes in the network. In such a way, each city contains one start node, one end node, and $2m$ entry and out nodes.



$m_{j,i}$ = the mode of the entry node of city *j*

$m_{j,o}$ = the mode of the out node of city *j*

$D_{o,j}^{m_{o,j}}$ = dray cost at origin node of city *j* using mode $m_{o,j}$

$I_{o,j}^{m_{o,j}}$ = inventory holding cost associated with drayage at origin node of city *j* using mode $m_{o,j}$

$D_{j,d}^{m_{j,d}}$ = dray cost at destination node of city *j* using mode $m_{j,d}$

$I_{j,d}^{m_{j,d}}$ = inventory holding cost associated with drayage at destination node of city *j* using mode $m_{j,d}$

$TR_{j,k}^{m_{j,k}}$ = travel cost from city *j* to city k using mode $m_{j,k}$

$I_{j,k}^{m_{j,k}}$ = inventory holding cost associated with travel from city *j* to city *k*

$T_j^{m_{j,i}m_{j,o}}$ = transfer cost from mode $m_{j,i}$ to mode $m_{j,o}$ at city *j*

$I_j^{m_{j,i}m_{j,o}}$ = inventory cost associated with transfer from mode $m_{j,i}$ to mode $m_{j,o}$ at city *j*

$C_{j,k}$ = total cost from the origin city *j* to destination city *k*

Suppose the network contains *n* cities, *m* transportation modes, city 1 is the origin city and city *n* is the destination city, then the cost formulation from origin to destination can be formulated as:

$$\begin{aligned} C_{1,n} = {} & \left(D_{o,1}^{m_{o,1}} + I_{o,1}^{m_{o,1}}\right) + \left(D_{n,d}^{m_{n,d}} + I_{n,d}^{m_{n,d}}\right) \\ & + \left(\sum_{\substack{\text{for each route} \\ \text{from city j to} \\ \text{city k in the path}}} TR_{j,k}^{m_{j,k}} + I_{j,k}^{m_{j,k}} \right) + \left(\sum_{\substack{\text{for each} \\ \text{city j in} \\ \text{the path}}} T_j^{m_{j,i}m_{j,o}} + I_j^{m_{j,i}m_{j,o}} \right) \end{aligned} \tag{1}$$

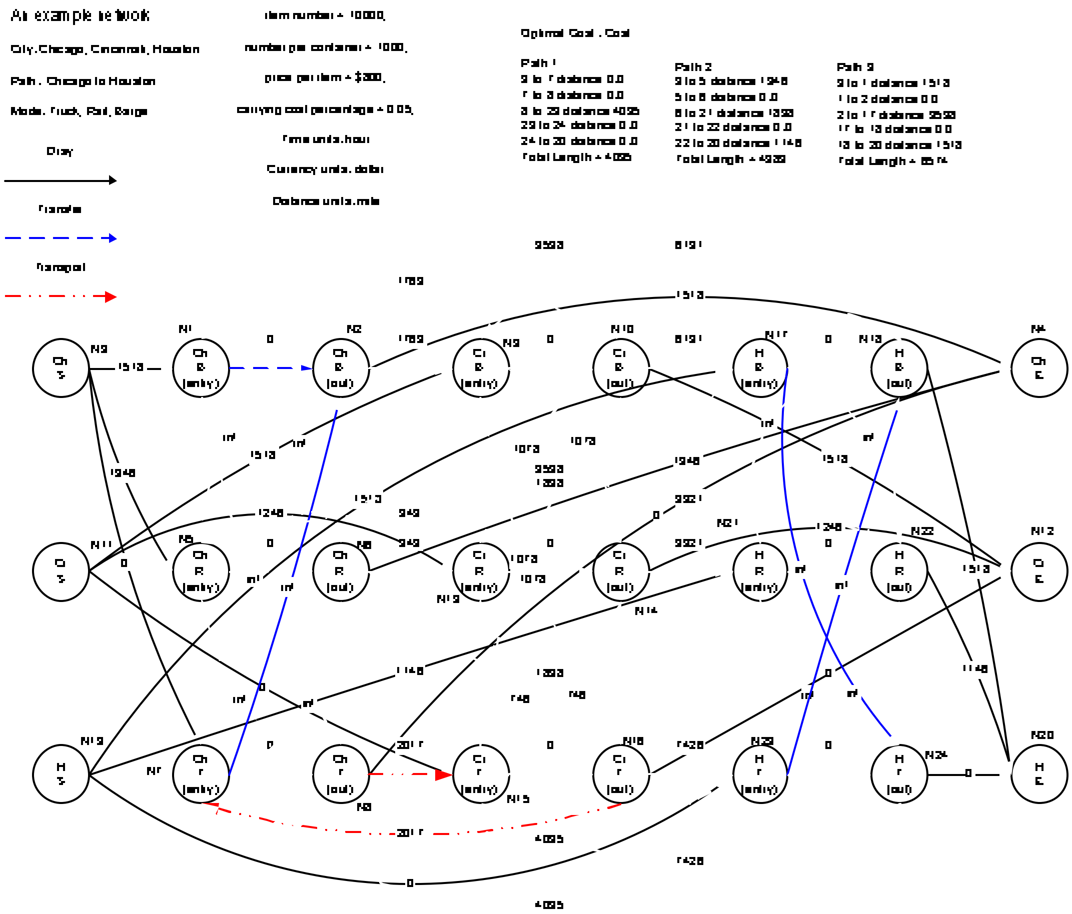
4 Case Study

In this section we use a simple example network consisting of three cities and three transportation modes to construct a intermodal transportation network as formulated in the last section and exhibit the results of WebShipCost. This illustration includes Chicago, Cincinnati, and Houston as the three cities in the transportation network. The available transportation modes are barge, rail, and truck. It is desired to transport 10,000 units of goods valued at \$800 per unit from the origin city of Chicago to the destination city of Houston. The carrying cost percentage is assumed to be 5% along with a container capacity of 1,000 units. We want to determine the three shortest paths to move goods from Chicago to Houston; therefore, *k* is set to 3. The optimal path set is shown in Figure 2.

Observation of system results in Figure 2 shows the three minimum cost paths from Chicago to Houston:

- Path One travels by truck from Chicago to Houston with a cost of \$4,035.
- Path Two travels by rail from Chicago to Houston with a cost of \$4,389.
- Path Three travels by barge from Chicago to Houston with a cost of \$6,574.

In this particular example, each path utilizes a single mode to travel from Chicago to Houston, and travel through Cincinnati is determined not to be cost efficient.



An example network

City: Chicago, Cincinnati, Houston

Path : Chicago to Houston

Mode: Truck, Rail, Barge

item number = 10000,

number per container = 1000,

price per item = $300,

carrying cost percentage = 0.05,

Time units: hour

Currency units: dollar

Distance units: mile

Optimal Goal : Cost

Path 1
9 to 7 distance 0.0
7 to 3 distance 0.0
3 to 23 distance 4095
23 to 24 distance 0.0
24 to 20 distance 0.0
Total Length = 4095

Path 2
9 to 5 distance 1248
5 to 6 distance 0.0
6 to 21 distance 1393
21 to 22 distance 0.0
22 to 20 distance 1148
Total Length = 4928

Path 3
9 to 1 distance 1513
1 to 2 distance 0.0
2 to 17 distance 2593
17 to 18 distance 0.0
18 to 20 distance 1513
Total Length = 6574

7 References

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