

# WebShipCost - Quantifying Risk in Intermodal Transportation

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## Abstract

The  $k$ -shortest path problem for intermodal transportation networks has a complex problem structure which is further complicated by uncertain time and cost parameters and multiple objectives. This paper presents a risk-based multi-objective decision model for intermodal transportation networks which allows decision makers to make trade-offs among multiple objectives and incorporate the inherent uncertainty into the decision making process. A thorough sensitivity analysis based on experimental design methodology is performed to evaluate the influence of the model factors on the decision results within particular interest regarding waterway transportation.

## Keywords

Intermodal transportation, Shortest path, Risk evaluation, Multi-objective decision model

## 1 Introduction

Intermodal transportation is the movement of goods or services by the coordinated and sequential use of two or more modes of transportation (Mahoney, 1985). Previous research (Li, et al., 2003) 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 waterway 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 alternative shortest paths in order of increasing cost or time. The user can then compare the alternatives to the shipper's requirements, such as service level or commodity type, and choose the best-suited path.

Currently, WebShipCost assumes that the cost and time elements stored in the database are precisely defined, while in reality the true values of future cost and time are never certain. Exploring the effects of this uncertainty on the WebShipCost output is important. While cost rates might be regarded as stable within a certain short time span, exploring the cost variability can provide an insightful view of cost elements' effect on the mode choice. A thorough sensitivity analysis will determine how fluctuations in the input data affect selections of the preferable shipping routes. Often shippers choose shipping options based on the perceived reliability of the service. The enhancements to WebShipCost will allow for the incorporation of risks associated with intermodal transport. Another limitation is that WebShipCost optimizes based on a single objective, either minimize cost or minimize time. A multi-objective optimization approach is needed along with methods for improved sensitivity analysis.

Due to the current limitations of WebShipCost, WebShipCost-Risk was developed to enhance prior research on intermodal transportation by providing a user-friendly, web-based application with the ability to handle uncertain input data and analyze risk. At the same time, it evaluates multiple objectives from shipper's perspective simultaneously and guides them to make trade-offs among these possibly contradicting objectives. Finally it performs a thorough sensitivity analysis by exploring the variation of input variables and its influence on the intermodal transportation route decisions.

## 2 Literature Review

For the last 30 years, research involving the choice of freight transportation mode has been steadily in progress. D'Este (1992) categorized freight transportation choice modeling approaches into three categories, input-oriented models, output-oriented models, and process oriented models. Input-oriented models relate to the range and relative importance of the various factors that influence carrier choice but do not give insight into the actual decision making

process (see Hall and Wagner, 1996; McGinnis, 1989). Output-oriented models are concerned with predicting the outcome of a particular decision situation. They tend to be predictive rather than explanatory models according to D'Este (1992). Shortest path network models, conjoint analysis, and Analytic Hierarchy Process (Saaty, 1980) have been used to formulate and solve the problem. Process oriented models attempt to explain how the various pertinent factors interact, as well as the nature of the environment within which the interaction occurs to produce the observed decision. Clemen and Reilly (2001) present influence diagrams as a means of structuring and illustrating decision making process. Many outcome oriented techniques such as decision trees, shortest path, and AHP could be applied to such structural models, assuming that the requisite data were available to yield a quantitative solution (Mangan, et al., 2001). Although many models have been developed for transportation mode choice, few papers have focused on quantifying the risk associated with transit process within a multi-objective situation.

### **3 Methodology**

#### **3.1 Decision Analysis Process Model**

In this section, the decision analysis process is depicted by an influence diagram. An influence diagram is particularly insightful for transforming the system in terms of the structural and causal relationships between system components. Figure 1 shows the decisions, uncertain events, outcomes, consequences and existing inter-relationships in an intermodal transportation system. The overall goal here is to achieve the cost, time, and reliability (minimize lost and damage probability of goods) objectives. These three objectives are influenced by uncertain events and route and node choice.

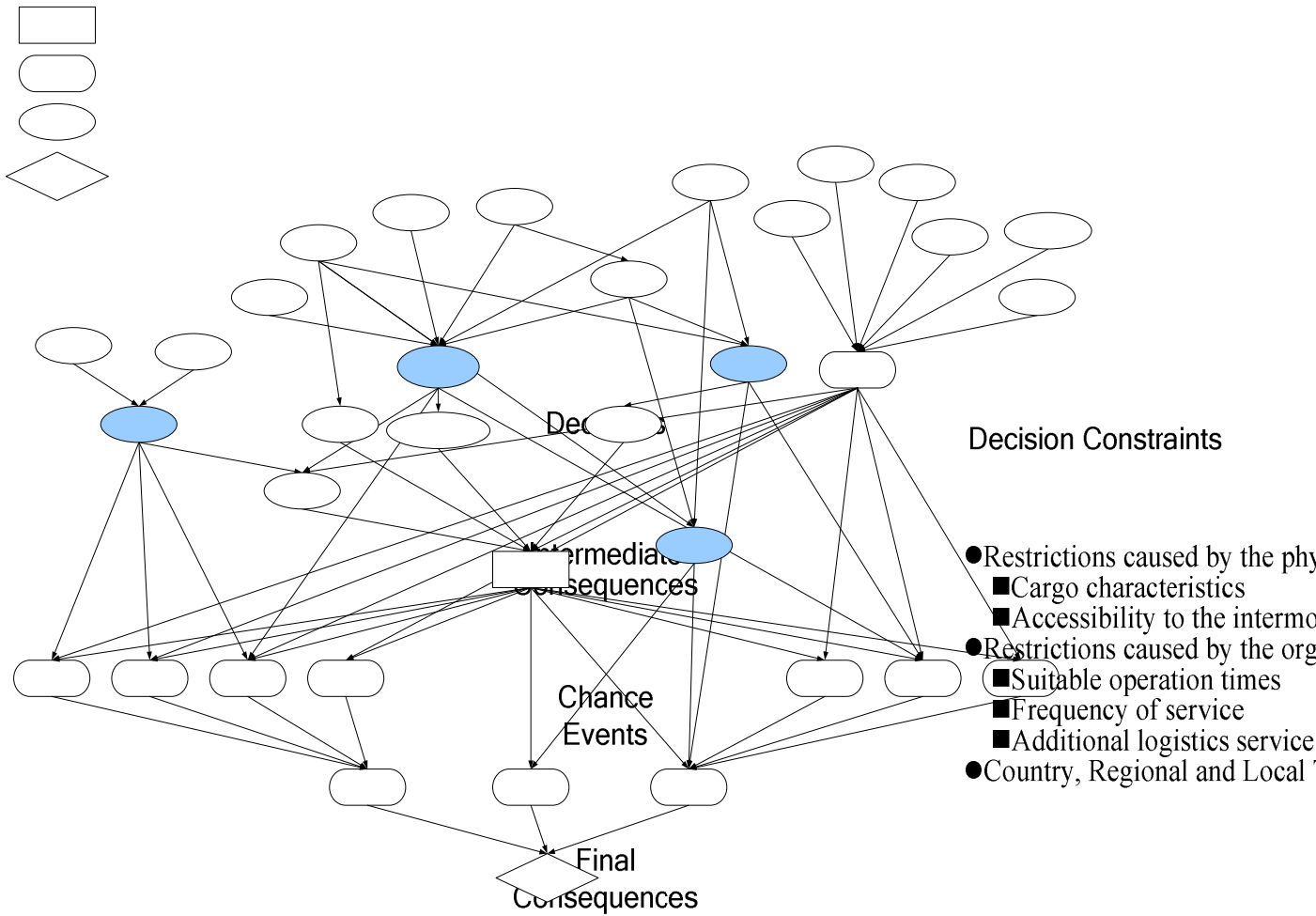
Four primary uncertain elements were identified from the literature review:

- Cost rates – Cost is incurred during the transport and transfer processes. Rates may fluctuate around the average value due to multiple economic and industrial environments during a given planning horizon.
- Traffic speed – Transport speed also may fluctuate around an average value for each of the primary modes – rail, truck, and barge. For example, weather conditions, congestions, road congestion, and road condition may directly affect the time it takes to transport cargo.
- Network route and node availability – Particular arcs in the transportation network may not be available due to inclement weather, accidents, lock closures, etc.
- Transportation safety – This is related to the reliability of the goods transit service associated with route.

Inputs variables within the intermodal decision system are controllable parameters specified by the decision maker. Input variables must be specified when the decision maker schedules a transport task. The following input variables for the WebShipCost shipping decision are identified:

- Origin city – location where the shipment is originating;
- Destination city – location where the shipment is terminating;
- Order size – number of units to be shipped;
- Container capacity – number of units each container can hold;
- Order cost – the value of the units ordered, based on the cost of each unit to the producer and order size;
- Holding cost rate – annual cost rate of carrying one unit in inventory.

As shown in Figure 1, cost rates may fluctuate when economic environment (e.g. competition level, demand level, etc.) changes. The user estimates the cost parameters and input variables prior to choosing the appropriate routes and modes. Network route and node availability must be considered in order to get a viable route. Uncertainties affect the dray cost, transfer cost, transport cost, and inventory holding cost, which are each components of the overall transportation cost. Transport speed is another important uncertain element. The user estimates the transport time and the probability that the goods will reach the destination on time based on the expected speed. The input variables such as order size, origin and destination are all influential elements in this estimate. The overall transit time includes transfer time, transport time, and dray time. Network route and node availability is also a basic uncertain element. Transport safety affects the shipper's choice in such a way that the shipper wants to minimize the lost and damage of goods (referred as reliability) during the entire transportation process.



**Figure 1 Influence Diagram for Intermodal Transportation Decision Analysis Process**

### 3.2 Problem Formulation

As previously mentioned, there are many uncertain elements in real world transportation route planning. These uncertain elements should be taken into account when the transportation decision makers plan and schedule the optimal shipment route. Uncertainty and associated risk are critical characteristics in such decision scenarios. Three objectives have been identified in the previous section. Since the reliability objective is not extremely significant in the containerized transportation situation, we focus on the cost and time related uncertain elements and goals here.

For a given pair of source  $s$  and destination  $t$  nodes, let  $P = \{(i_0 = s, j_0), (i_1, j_1), (i_2, j_2), \dots, (i_k, j_k = t)\}$  be the set of arcs that define the path where  $j_{k-1} = i_k, k \in 1, 2, \dots, k$ . For the cost objective, let  $C_{ij}$  be the random variable that represents the cost associated with arc  $(i, j)$ . Suppose  $C_{ij}, (i, j) \in P$  are independent random variables. Let  $C$  denote the total cost of the path  $P$ , i.e.  $C = \sum_{(i,j) \in P} C_{ij}$ . Let  $p^*$  denote the path which the decision maker prefers. Here

the decision maker desires a path that minimizes the expected total cost. In addition, decision makers would quite naturally want to control the associated risk. As such it could be natural to find the path that minimizes the standard deviation of the cost and/or minimizes the chance of exceeding an upper cost threshold. Therefore three sub-objectives are taken into consideration: the mean value of the total cost, the standard deviation of the total cost, and the probability that the total cost associated with the selected route are within an acceptable threshold.

Terminal Capacity

Economic Environment

Industrial Environment

Cost Rate

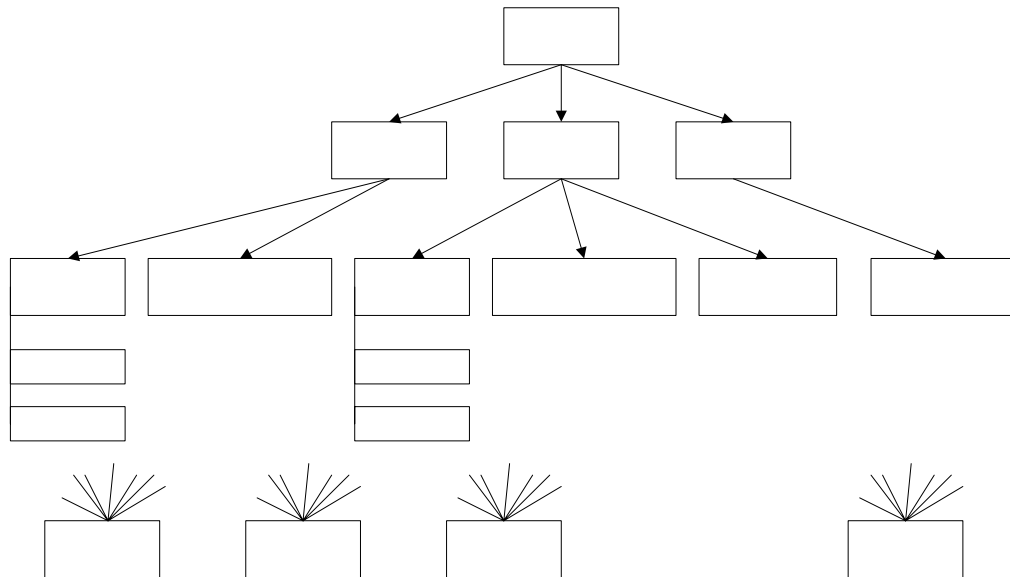
Let  $C_u$  be an upper cost threshold specified by the user for this decision problem. The upper cost threshold represents the highest cost for the path that the decision maker is willing to accept. After we obtain deterministically optimal path candidates, Monte Carlo simulation is used to simulate the uncertainty and provide two sub-objective values for each path, i.e. the mean value of the total cost and  $\Pr(C < C_u)$ .

For the time objective, three sub-objectives similar to those defined for the cost objective apply here. Formulation is also similar to the cost objective with the exception of an additional sub-objective, minimize the Just-In-Time (JIT) probability associated with the path. Such consideration is common in reality as the decision maker identifies the time span when they wish the goods arrive and they can only afford a certain amount of diversion from that time. Let  $T_l$  and  $T_h$  be the lower and upper bound of the JIT time span specified by the decision maker,  $\Pr(T_l < T < T_h)$  should be minimized.

### 3.3 AHP Method

The Analytic Hierarchy Process (AHP) is widely used to solve multi-objective decision problems. The power of AHP lies in its ability to structure a complex, multi-attribute, and multi-period problem hierarchically. Applying AHP to solve the path alternative decision problem consists of five stages: 1) Decision hierarchy construction, 2) Attribute priority determination, 3) Alternative weight determination, 4) Consistency computation, and 5) Overall priority weight determination.

The decision hierarchy graph is shown in Figure 2. The top level of the hierarchy diagram refers to the overall goal of selecting the best path from the optimal path set. The second level contains the three primary objectives for path evaluation: cost, time, and reliability. Each of these was then decomposed to subobjectives as shown in the third and fourth level. The bottom level consists of the  $k$  path alternatives.



**Figure 2 Decision Hierarchy**

Once the hierarchy is established, priorities should be established for each set of elements at every level of the hierarchy. The user of the WebShipCost might be asked to evaluate a set of elements at one hierarchy level in a pairwise fashion regarding their relative importance with respect to each of the elements at the next higher level of the hierarchy. The next step is to determine the priority of each of the alternatives with respect to each of the attributes. Typically, these priorities are also set using a pairwise comparison process. In addition, because all of our performance data are quantifiable, we can directly compute our performance data for multiplication by the priority weight values. At this point, consistency computation and overall priority weight determination can be performed using the standard AHP procedure. The most preferred path has the maximum overall weighted performance.

### 3.4 Methodology

The methodology for choosing the most desirable route in the intermodal transportation network is as follows:

- Step 1. Construct the intermodal transportation network according to the specific decision scenario. In other words, abstract the real network into nodes and arcs;
- Step 2. Decorate each arc with expected cost value  $E(C_{ij})$ , where  $C_{ij}$  is a random variable denoting the uncertain cost associated with the arc. Suppose  $C_{ij}$  is independent with each other. For path  $P$ , the expected value of total cost equals the summation of the expected cost value of each arc in path  $P$ , i.e.  $E(C_p) = \sum_{(i,j) \in P} E(C_{ij})$ ;
- Step 3. Run the double sweep algorithm to get first  $k$  least cost path set  $P_c = \{p_{c1}, p_{c2}, \dots, p_{ck}\}$ ;
- Step 4. Decorate each arc with the expected time value  $E(T_{ij})$ , where  $T_{ij}$  is a random variable denoting the uncertain time associated with the arc. Also suppose the independence among  $T_{ij}$ . For path  $P$ , the expected value of total time equals the summation of the expected time value of each arc in path  $P$ , i.e.  $E(T_p) = \sum_{(i,j) \in P} E(T_{ij})$ ;
- Step 5. Run the double sweep algorithm to get first  $k$  least time path set  $P_t = \{p_{t1}, p_{t2}, \dots, p_{tk}\}$ ;
- Step 6. Combine the path set  $P_c$  and  $P_t$  into a candidate path set  $P = \{p_{c1}, p_{c2}, \dots, p_{ck}, p_{t1}, p_{t2}, \dots, p_{tk}\}$ ;
- Step 7. Run Monte Carlo simulation on each path of path set  $P$ , compute the performance matrices;
- Step 8. Using AHP method to get the final optimal path set ranked in the descending order of the overall weighted evaluation.

## 4 Sensitivity Analysis

There are many factors that affect the rankings of preferable routes. It is unclear what influence these factors have on the decision results. Of particular interest, under what conditions does the barge mode demonstrate the superiority over the other modes? These questions are addressed through a sensitivity analysis.

The experiment is conducted using a two level full factorial design investigating nine factors which are based on the general transportation knowledge. These nine factors are: 1) Weight of the cost / time / reliability, 2) Cost threshold, 3) Time threshold, 4) Time lower & upper bound, 5) Distance between origin and destination cities, 6) Order size, 7) Container capacity, 8) Item cost, and 9) Holding cost rate. Here threshold values are set in order to compute the performance matrices such as “Probability within cost/time threshold” depicted in Figure 2. Table 1 shows the factor setting of the experiment. The results of this experiment are listed in Table 2 and Table 3 below.

**Table 1 Factor Level Setting**

Factor	Low	High
Cost, time, reliability weights	0.2, 0.4, 0.4	0.6, 0.2, 0.2
Cost threshold	0.5	1.0
Time threshold	0.5	1.0
Time lower & upper bound	0.2	0.5
Distance between origin and destination cities	<=665 mile	>665 mile
Order size	1,000	5,000
Container capacity	100	500
Item cost	\$10	\$50
Holding cost rate	0.05	0.25

In order to evaluate the influence of the model factors on the decision results, the following three responses are specified:

- Percentage of each cost and time element in the resulting most preferable path;
- Number of arcs of each mode type in the resulting most preferable path;
- Distance percentage of each mode type in the resulting most preferable path.

**Table 2 Cost & Time Percentage**

Cost & Time Percentage	Mean	Standard Error
Dray Cost Percentage	0.167	0.005
Transport Cost Percentage	0.571	0.012
Transfer Cost Percentage	0.224	0.006
Inventory Carry Cost Percentage	0.037	0.003
Transfer Time Percentage	0.027	0.002
Transport Time Percentage	0.973	0.002

**Table 3 Response Results**

Response	Mean	Standard Error
# of Barge Arc Percentage	0.588	0.022
# of Truck Arc Percentage	0.260	0.019
# of Rail Arc Percentage	0.152	0.015
Percentage of Barge Distance	0.588	0.022
Percentage of Truck Distance	0.261	0.019
Percentage of Rail Distance	0.151	0.016

Observation of Table 2 indicates that Transport and Transfer Costs are the predominant cost components of the total cost of the optimal path. Transfer time has a very low impact on the total time associated with the optimal path. Table 3 indicates that Barge (in terms of arc percentage and distance) is a major player under the right conditions. Examination of detailed results indicates that the weight of cost has a large impact on the number of barge arcs as expected. When the weight of cost increases, the barge becomes the dominate mode in the optimal path because of its much lower shipping rate compared to truck and rail rates. When the time threshold becomes more relaxed, barge is more competitive as shown by the additional barge arcs entering the optimal path. This is reasonable as the transport time for barge is longer and likely has larger variation within the total transport time. Time lower & upper bound has the similar effect on the response as time threshold.

## 5 Conclusion and Extensions

Prior research has been enhanced though the development of a risk-based multi-objective decision system for intermodal transportation networks which allows decision makers to trade-off among multiple objectives and incorporate the uncertainty into the decision making process. Current work seeks to expand WebShipCost to interactively accept user input transportation network data, integrate with a Geographical Information System (GIS), and provide intermodal shippers with graphical and user-friendly information to improve decision making.

## 6 Acknowledgment

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