WebShipCost – Quantifying Risk in Intermodal Transportation

MBTC 2035

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16. Abstract

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1 PROBLEM STATEMENT

This section presents the motivation and description of this project and gives an overview of previously-conducted projects that have laid the groundwork for this research.

This project addresses the problem of Arkansas and other states' underutilized waterway transportation networks. Part of the underutilization of waterway transportation in the U.S. stems from a lack of understanding by shippers of the cost and time trade-offs associated with utilizing waterway transportation as part of an intermodal delivery system. In particular, users of waterway transportation are faced with uncertain transport times and additional risk associated with meeting intermodal connections. There exists the need for easy to use and widely available models that can illustrate the advantages and disadvantages of barge transportation within the context of an intermodal transportation network.

Prior MBTC research projects (MBTC FR 1036, MBTC FR 1079, MBTC FR 1100-1, and MBTC FR 2024) contributed to the development of WebShipCost, a WWW-based implementation of cost models that describes the costs incurred by all activities (rail, truck, and barge) within an intermodal transportation network. WebShipCost allows online determination of the ranked shortest paths in terms of cost or time from an origin point to a destination point within the network and enables shippers to understand the trade-offs associated with barge and container-on-barge transportation. The information below summarizes the cost elements used in WebShipCost. This analysis is based on data from research at University of Arkansas (Trusty & Malstrom, 1998) and the ShipCost user's manual (Boardman & Malstrom, 1998). The information is also derived from a detailed analysis performed for the Defense Logistics Agency (Rossetti et al., 2000).

WebShipCost performs its analysis based on a formulation of the total transportation cost and time. Four cost elements considered in the model are *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 value of the 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.

Time elements formulated in the model include *travel time*, *transfer time* and *dray time*. The time of moving goods from loading site to unloading site by selected travel mode is defined as *travel time*. Travel time is computed from distance defined in barge, rail, or truck miles divided by the mode average speed. Transfer time and dray time are defined in a similar way as in the cost scenario. The time of transferring goods from one mode of travel at the load/unload site to another travel mode is the *transfer time*. *Dray time* is incurred for moving goods to/from a stationary site from/to the loading site for transport. Data for *transfer time* and *dray time* are from a variety of data sources (Rossetti & Nachtmann, 2003).

WebShipCost currently consists of a database, the double-sweep algorithm for solving the K shortest paths problem, and a WWW based user interface. After the origin, destination, shipment information, and single objective (minimize total cost or total time of the shipment) have been specified by the user, the system creates the network structure, performs the algorithm to derive the resulting paths, and displays the path alternatives in ascending order of cost or time. Then, the user can evaluate the alternatives considering the associated shipment's requirements, such as service level or reliability, and choose the best-suited path. The user is allowed to define other networks to be analyzed by WebShipCost.

Currently, WebShipCost assumes that the cost and time elements stored in the database are precisely defined, while in reality the true values of these future costs and times 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. This enhanced risk and sensitivity analysis will help to better educate shippers in and around the State of Arkansas about the advantages of barge transportation and how these advantages might be put to use for their company.

Another limitation is that WebShipCost optimizes a single objective, either minimize time or minimize cost. A multi-objective optimization approach that incorporates multiple objectives is needed along with methods for improved sensitivity analysis.

Due to the current limitations of WebShipCost, this project seeks to enhance it and other prior MTBC research on intermodal transportation by providing a user-friendly, web-based application with the ability to handle uncertain input data, which will allow shippers to analyze risk. At the same time, it evaluates multiple objectives (minimize cost, minimize time, and maximize reliability) from shipper's perspective simultaneously and guides them to make trade-offs among these frequently contradicting objectives. Finally it performs a thorough sensitivity analysis by exploring the variation of input variables and its influence on the intermodal transportation route decision results, especially on the barge modal choice.

The outline of this report is as follows: A literature review on intermodal transportation, decision making models and related topics is presented in Section 2. Section 3 discusses the solution methodology including problem structure modeling, uncertain elements identification, problem formulation, multi-objective model construction and supporting uncertainty data assumptions. In Section 4 a thorough sensitivity analysis is performed, and statistical analysis shows the influence of the input factors on the optimal routing decisions. Section 5 presents some design and implementation issues of the WebShipCost–Risk application and demonstrates the user experience. Section 6 summarizes with conclusions and potential further research areas.

2 LITERATURE REVIEW

2.1 Introduction

There are five basic modes of transportation: water, air, highway, rail, and pipeline. While this research focuses on three of these modes (water, highway, and rail) as these are the primary modes used in the State of Arkansas and surrounding areas, a discussion of all modes is important. The combination of all possible modal arrangements produces many feasible methods for moving goods (Jennings & Holocomb, 1996). Each option has its unique advantages and disadvantages for freight movement. In recent years, there have been developments in transportation methods and linking them with various other modes. Intermodal transportation can be defined as the movement of goods or services by the coordinated and sequential use of two or more modes of transportation. Listed below are some examples of vehicles influenced by the medium in which they operate, and thereby constituting modes are listed below (Mahoney, 1985).

- Water: ocean vessels, coastal vessels, and inland waterway barges;
- Air: airplanes;
- Land: rail freight trains, highway trucks, and pipelines.

The basic elements of the intermodal freight system are shown in Table 2-1.

Table 2-1 Elements of Intermodal Freight System

(Erickson, Grenzeback, & Schrieber, 1999)

	Air	**Rail**	**Water**	**Road**
Carriers	Air Cargo Carriers	Railroads	Shipping Lines	Motor Carriers
Conveyance	Airplanes	Trains	Ships and Barges	Trucks
Terminal	Airports	Rail Terminals	Ports	Truck Terminals
Infrastructure	Airways	Railways	Sea and Inland Waterways	Roadways

There are single mode transfers as well as intermodal transfers of freight between vehicles. A list of characteristics describing a single mode transfer is given below:

- Single mode transfers are typically easier to accomplish than intermodal transfers;
- The vehicles are alike and operating in the same medium;
- Single mode transfers are typically easier to manage than intermodal transfers;

Although there are advantages of single modal transportation of goods, intermodal transportation can provide an efficient means of transportation. In recent times, intermodality has proved to be an invaluable tool for the shipment of goods. It offers a greater flexibility of routings and costs can be lowered by a precise combination of carriers and vehicles and standardization (Harps, 1995; Mickle & Burns, 1978).

It has been observed that nearly forty major commodities are involved in intermodal transportation. The listing consists of dry and liquid materials. The viability of transferring strongly depends on the characteristics of the commodities being transported. First among the characteristics of transferring commodities is that they all move in large volumes, or are large in physical size in their transported state. An inherent advantage of barge, rail, or pipeline is carrying capacity; hence it is expected that transfer activities involving these modes would seek to utilize this aspect (Jennings & Holocomb, 1996).

The product handling ability is another issue that may determine a preferred commodity characteristic for transfer practices. Most of the commodities listed are industrial or commercial in nature and thus are to be transported in large volumes and/or sizes. The products are items used by industry as either raw materials or components for production of other commodities for the consumer or commercial market. These commodities are listed in Table 2-2 (Jennings & Holocomb, 1996).

Table 2-2 Commodities Involved in Intermodal Transportation

Dry Flowables	Liquid Flowables	Non-Flowables
Alumina Ore	Asphalt	Aluminum Bars
Ammonium Nitrate	Caustic Soda	Aluminum Ingots
Cements	Chemicals (Misc.)	Bagged Barite
Coal and Coke	Diesel Fuel	Brick
Fertilizers	Gasoline	Coiled Steel
Flour	Methylene Chloride	Lumber
Grain	Motor Oils	Machinery
Grain Products	Processing Oils	Newsprint
Gypsum		Pipe
Iron Sulphite		Scrap Metal
Plastic Pellets		Steel Parts
Polypropylene Powders		Steel Wire
Rock		Structured Steel
Roofing Granules		
Salt		
Sand		
Zinc Ore		

The recent growth in intermodal trade has increased public and private interest in the development of intermodal transportation and logistics facilities designed to handle new traffic. River and canal based cities formed the back bone of the industrial revolution in North America during the eighties. Advances in multimodal transportation spurred by growing international markets, global outsourcing of materials and production, formation of regional trading blocks, the increasing importance of time-based competition, and rising fuel costs are fostering new potential areas of economic power. Facilities that integrate large volume air shipments with rail and motor transportation, as well as advanced telecommunications and information systems, production/assembly capabilities, and distribution, are supporting the development of new economic power bases and trade patterns (Stank & Roath, 1998).

Future intermodal growth, however, is not fully assured. There have been a number of improvements in transportation and information technology that have helped to increase the efficiency of intermodalism. But market pressures and the demand for increased services suggest the need for even greater investment in infrastructure development. Some constraints to intermodal development are found within the carrier industry. Due to resource shortages, carriers have had to develop partnerships to meet minimum customer expectations and maintain a competitive edge in intermodal service offerings. While customers have been relatively satisfied with joint service offerings, the involvement of multiple partners with different goals and objectives has created organizational difficulties (Stank & Roath, 1998).

2.2 Intermodal Railroad – Truck Transportation

Intermodal railroad-truck (IRT) service is where one or more motor carriers provide the short-haul pick up and delivery service part of the trip and one or more railroads provide the long haul part. The primary equipment involved is truck trailers/containers as intermodal units, which are carried on railroad cars. IRT is used for both domestic and international movements (Harper & Evers, 1993).

IRT combines the door-to-door convenience of trucks with the high volume, long haul, and economics of railroads. As compared to alternative services, transit time and rates may be lower, thus serving as a potential advantage for the shipper. In addition, as IRT represents competition to other modes, it can have the effect of improving service and lowering rates offered by other modes (Harper & Evers, 1993). In the late 20th century, the number of intermodal units loaded by U.S. railroad increased from 3.0 million units to 6.2 million units, showing growth of 106%.

Accordingly, IRT has become a major source of revenue for railroads; however, despite the rapid growth during the 1980s, IRT still accounts for only 6% of total intercity freight traffic (Harper & Evers, 1993). For IRT to be a viable alternative, it must be available to shippers and receivers, the quality and cost of the IRT service must be competitive with other modes, and IRT must be accepted and utilized by the shippers (Harper & Evers, 1993).

One of the primary disadvantages of IRT is high door-to-door transit time, which can be caused by several factors. There can be difficulty of making connections between modes in a reasonable amount of time. Poor train scheduling and excess need to assemble and disassemble trains also adversely affect transit time. In addition to the mentioned disadvantages, the two mode system often requires that a shipment move not directly from door-to-door, but instead indirectly through railroad terminals at each end. Furthermore, railroad service sometimes involves more circuitous routing when compared with the Interstate Highway system. Finally, when more than one railroad is involved, a shipment must be interchanged with another railroad, which is often a time consuming process (Harper & Evers, 1993).

Freight damage is another concern about IRT service. Because of the excessive handling involved in transferring modes, the cars switching impact, and the slack action in train operation, IRT service has had a poor damage record, though it has been reduced considerably in recent times. Another associated problem is the liability for loss and damage assumed by the carriers. IRT movements usually involve more than one carrier; hence determining who is liable for the damaged freight can be problem since it depends upon where the loss or damage occurred (Harper & Evers, 1993).

While IRT can be a service disadvantage, price often becomes the main selling point in anticipation that the customer will consider it to be more important than service. The growth forecast for intermodal transportation created new challenges and opportunities for the railroad industry. Railroads and third-party partners have targeted highway truckload business for future sales gains (Johnston & Marshall, 1993).

2.3 Waterway Transportation

Inland water carriers are generally used for long haul bulk movements because their routes are fixed geographically, and their business is mostly bulk commodity (Mahoney, 1985). In recent past, there have been developments in waterway transportation in the U.S. The prominent changes occurred in the linking of other modes of transportation to waterway transportation systems (Trusty & Malstrom, 1998).

Maritime (water) transport, similar to land and air modes, operates on its own space, which can be at the same time

- Geographical by its physical attributes;
- Strategic by its control;
- Commercial by its usage.

There are two major elements of maritime transportation, rivers and oceans. Although they are connected, each represents a specific domain of maritime circulation. Maritime traffic has evolved considerably over the last decades especially through growth in transpacific trade. By establishing commercial linkages between continents, maritime transport supports a considerable traffic that covers 90% of the intercontinental transport demand of freight. The strength of maritime transport depends upon the capacity and on the continuity of its traffic and not on its speed. Railway and road transportation are not able to support traffic at such a geographical scale and intensity. Heavy industrial activities that use bulk raw materials are generally adjacent to port sites, to get the benefits from load breaks. The average haul length is about 4,200 miles.

In the U.S., waterways provide the most economical and environmentally sound mode of moving goods and commodities. Inland waterways carry approximately 15% of total freight transported in the U.S. The annual value of goods exchanged between 24 states linked with waterways exceeds $100 billion (Nachtmann, 2002). The map of the U.S. waterways is shown in Figure 2-1 and the freight shipments by mode is shown in Table 2-3 (U.S. Department of Transportation, Federal Highway Administration Online Public Data, 2002).

Figure 2-1 U.S. Inland Waterways

(Navigation Information Connection, http://www.mvr.usace.army.mil/navdata)

Table 2-3 U.S. Freight Shipments by Mode (U.S. Department of Transportation, Federal Highway Administration Online Public Data, 2002)

Mode	Value		Tons	
	Billions $	%	Millions	%
Truck	7429	83	10859	71
Rail	646	7	2311	15
Water	163	2	1219	8
Air	1083	8	18	0.1
Pipelines & Other	N/A	N/A	864	5.7
Total	9320	100	15271	100

The strength of a transportation system lies in its diversity, with each mode having its own specific advantages. The motor carriers have the ability to provide door to door service, water carriers can handle bulk commodities safely at a very low cost; and rail companies can transport a broad range of commodities over long distances. Efficient freight transportation systems can play a positive role both in the economic life of industrialized countries and the day-to-day lives of their citizens. Even though, these transportation systems are essential to a modern society, and there are substantial economic benefits to be realized, there can be also significant negative environmental impacts including preemption of land, disruption of topography, consumption of energy and other resources, and both noise and air pollution. Waterborne transportation proves a much better option compared with others since it requires significantly less fuel than rail or truck and air pollution resulting from water transportation is almost negligible (U.S. Department of Transportation, Maritime Administration Public Report, 1994). The cost per ton mile for a barge is only 0.73 cents, compared to 2.28 cents for rail, and 9.15 cents for trucking as shown in the chart Figure 2-2 (Wilson, 2000). Additional benefits are listed next (U.S. Department of Transportation, Maritime Administration Public Report, 1994):

- An improved natural environment for wildlife, parks and recreational areas,
- Generation of clean and renewable hydroelectric power,
- Reduced soil erosion, and
- Flood reduction.

Because of these advantages, the intermodal traffic across the waterways is increasing.

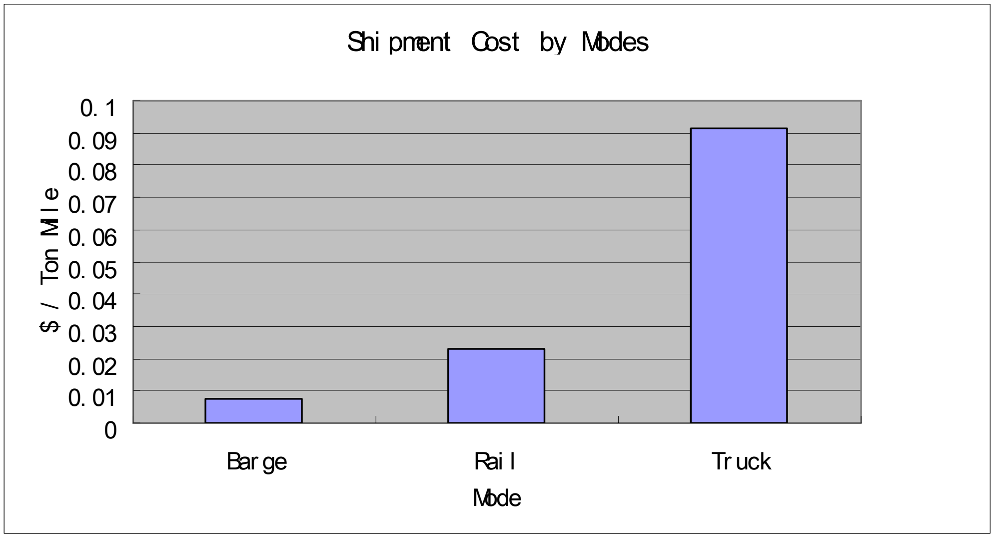


Figure 2-2 Shipment Cost by Modes

2.4 Intermodal Transportation Decision Making

For the last 30 years, research involving modeling the freight transportation choice has been steadily in progress. There is a substantial literature dealing with such decision problems. D'Este (1992a) categorized the various freight transportation choice modeling approaches into three broad categories, i.e. input-oriented models, output-oriented models, and process oriented models.

Input-oriented models attempt to explain the behaviors of decision makers by investigating various factors that influence freight transportation choice. Basic statistical techniques are widely used to analyze the factor importance and build relational models (Mentzer & Kahn, 1995). An example is D'Este (1992b) who identified the relative importance of the various choice factors and their interactions in carrier selection through a survey of companies purchasing shipping services across the Bass Strait. Drawbacks of input oriented models are that they do not provide insight into the actual decision making process.

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

(1992a). For example, Rossetti & Nachtmann (2003) formulated the intermodal transportation routing problem as a *K*-shortest path network model with time and cost values on each arc. Decision trees, conjoint analysis, and the Analytic Hierarchy Process (Saaty, 1980) have also been used to formulate and solve the problem (Mangan, Lalwani, & Gardner, 2001). Output-oriented models focus on the mathematical formulation aspect of the problem rather than the interactive behavior of the decision system. Therefore, like input-oriented models, they do not provide understanding of the actual decision making process.

Unlike the previous two models, process oriented models focus on identifying the interactive relations among pertinent decision factors. D'Este (1992c) constructed a framework to represent the stages of the decision process and the interaction of factors that influence the shipping managers in the context of RO/RO ferry trade. This model was built based on a survey of the shippers. Clemen & Reilly (2001) present influence diagrams to structure and illustrate the decision making process. Many outcome oriented techniques, such as decision trees, shortest path, AHP, etc., could also be applied to such structural models, assuming the requisite data were available to yield a quantitative solution (Mangan, Lalwani, & Gardner, 2001).

3 METHODOLOGY

In this section, we first describe the problem using a decision analysis process model. Then we illustrate the uncertainty formulation. We also present the application of the Analytic Hierarchy Process (AHP) to build the multi-objective decision model and incorporate the uncertainty factors into this model. Finally we discuss our uncertainty data assumptions and optimal path set evaluation.

3.1 Decision Analysis Process Model

As previously stated, the intermodal transportation problem deals with the situation where multiple modes – e.g. truck, rail, and barge – are used to move cargo from an origin to a destination. In an intermodal transportation system, individual transportation modes are connected from origin to destination in such a way that meets the needs of the shippers efficiently and effectively. The chosen modes affect the overall performance measures of the transportation system such as the total cost and the total delivery time. Therefore the key issue is how to select the most appropriate transit mode and route in the intermodal transportation network so as to optimize the chosen performance measures.

Like many other complex decision making problems, a variety of elements cause the intermodal transportation decision to be difficult to make. The most pertinent are as follows:

- Complexity – There are many factors involved in the intermodal decision analysis process. Some factors are user specified input data such as shipment size while others include external uncertainty factors and constraints of the transportation network. It is difficult for the decision maker to handle the complex interactions between a large number of factors.
- Uncertain events – Uncertainty brings risk into the decision process. In this scenario, there are many uncertain events that may occur within the transportation network, e.g. transfer time may not be estimated accurately, additional cost may incurred for delays, a portion of the route may be closed for the inclement weather, etc.
- Multi-objectives – When multiple objectives are involved in the decision making process, decision makers must trade off benefits in one area against costs in others. The goal in this

problem is multi-objective where it is necessary to evaluate the decision within a multi-objective decision model to optimize the performance measures.

Multi-objective optimization and decision analysis provide the tools and effective methods to deal with such elements. The first step for the decision maker is to identify the decision situation and understand what their objectives are. Based on the previous MBTC research projects (MBTC FR 1036, MBTC FR 1079, MBTC FR 1100-1, and MBTC FR 2024) and literature review (Tsamboulas & Kapros, 2002, LOGIQ, 1999, and Wood & Johnson, 1995), the basic decision elements are presented in the following subsections.

3.1.1 Uncertain Events

There are many uncertain elements that exist in an intermodal transportation network and are involved in the decision making process. Based on our previous research and literature review, we have grouped these into four categories: cost rates, traffic speed, network route and node availability, and transport safety. Each of these uncertainties may be caused by specific uncertain events.

- Cost rates – Cost is incurred during the transport and transfer processes. In realistic transportation planning scenarios, rates may fluctuate around the average value due to multiple economic and industrial environments, such as competition and fuel price 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, traffic congestion, and road condition may directly affect the time it takes to transport cargo. Weather does affect all modes, (i.e. truck, rail, and barge). Water transportation in the colder regions of the U.S. shuts down completely during winter months. A bad snowstorm can bring air, truck, and rail traffic to a halt. Flooding is another weather phenomenon that interferes with transport operations.
- Network route and node availability – Sometimes a particular network arc may not be available for reasons such as inclement weather, accidents, lock closures, road maintenance, and river dredging, etc. Terminal capacity, as some terminals may not have enough capacity

to handle goods with large order size, may cause a node not to be available for goods transfer.

- Transport safety – This is related to the reliability of the goods transit service associated with a route.

3.1.2 Influence Diagram

An influence diagram is particularly insightful for bringing out the transformation of the system in terms of the structural and causal relationships between system components. In this section, the decision analysis process is depicted by an influence diagram. The diagram shows the decisions, uncertain events, outcomes, consequences and existing inter-relationships in an intermodal transportation system. The overall goal is to achieve the cost objective, to achieve the time objective, and to achieve the reliability objective, i.e. to minimize lost and damage probability of goods. These three objectives are influenced by uncertain events, user input variables (see below), and route and node choice. As identified before, four uncertain elements are cost rate, traffic speed (time), network route & node availability, and transport safety. All these basic uncertain events are influenced by variety of other specific uncertain elements.

Inputs variables are controllable parameters within the decision system. For each transportation task, the input variables must be specified by the decision maker. The following input variables for the intermodal shipping decision were identified. These are the same input variables as in the WebShipCost application:

- Origin city – the location where the shipment is originating;
- Destination city – the location where the shipment is terminating;
- Order size – the number of units to be shipped;
- Container capacity – the number of units each container can hold;
- Item 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

When the decision maker schedules a transport task, input variables must be specified.

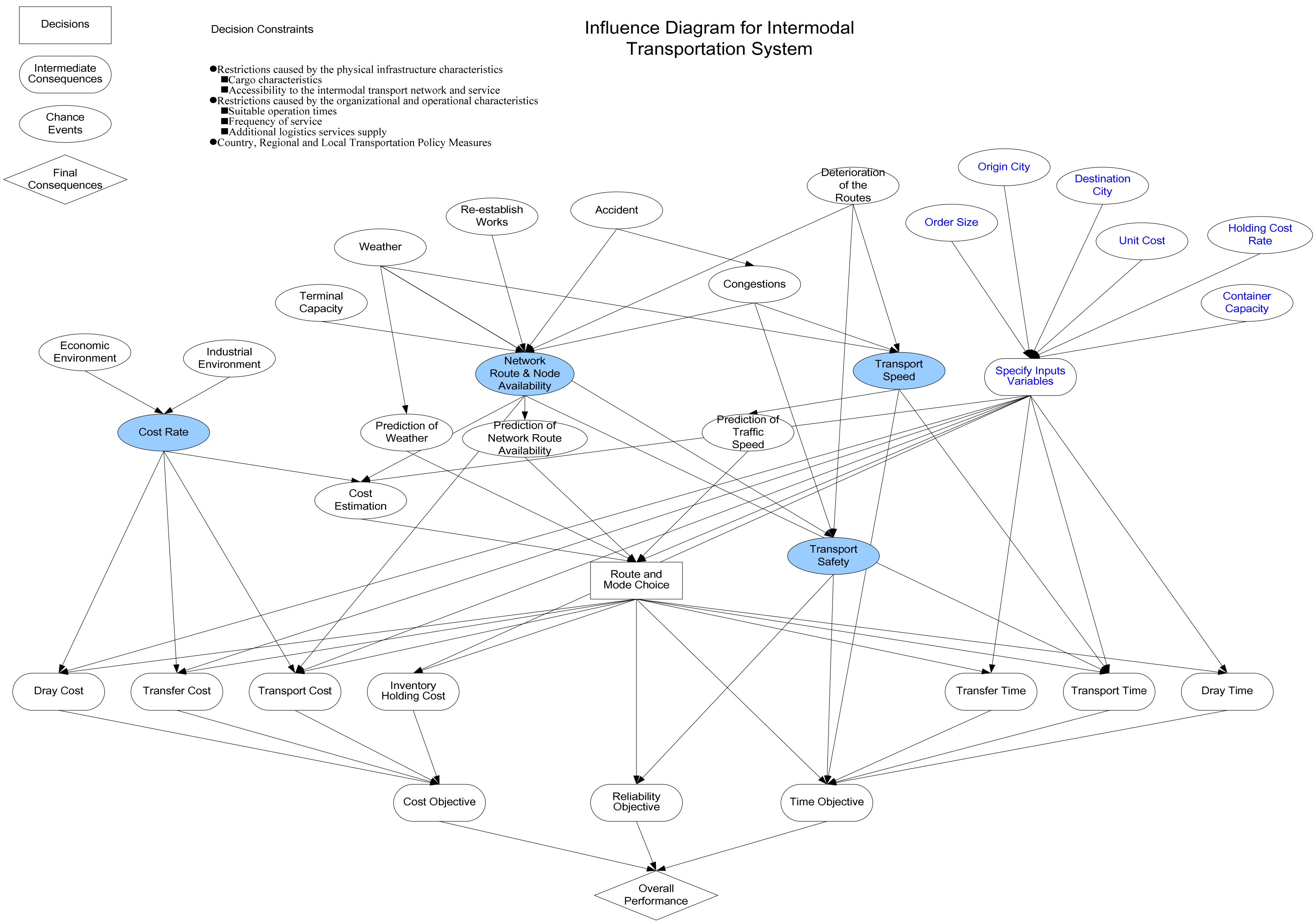


Figure 3-1 Influence Diagram for Intermodal Transportation Decision Analysis Process

As previously discussed, cost rate is one basic uncertain element. The user estimates the cost according to the cost rate and input variables such as origin city, destination city, and order size before choosing the appropriate routes and modes. Network route and node availability should also be considered in order to get a viable route. Many uncertain events affect this availability. Depicted in the diagram are terminal capacity, weather, re-establish works, accident, and deterioration of the route. For example, water transportation in the colder regions of the U.S. shuts down completely during winter months. These 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 significant 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 to as reliability) during the whole transportation process.

In our project, we did not model all these system components. For example, network route and node availability is hard to model because representative data are scarce. Typically decision makers have cost and time as their primary concerns; therefore we will focus on these two objectives in the next section.

3.2 Problem Formulation

In the previous section, the intermodal decision was depicted as an influence diagram. This section presents the illustrated mathematical formulation of the uncertain elements and decision objectives in order to provide the basis for our analysis.

In the intermodal transportation network of WebShipCost, the arc lengths separately represent the time or cost values associated with the corresponding transportation activities such as transfer, transport, etc. Because all the data are assumed to be precise and known, there is no uncertainty to deal with. Therefore, the problem can be formulated as a deterministic shortest path problem. Single shortest path problem is a special case of *k*-shortest paths problem: Given a directed network $G = (N, A)$, where $N = \{1,2,...,n\}$ is the node set, and $A = \{(i, j) \mid i, j \in N\}$ is the arc set, with arc lengths $c_{ij}(c_{ij} \geq 0)$ associated with each arc $(i, j) \in A$. The network has a distinguished source node *s* and a destination node *t*. The length of a directed path is the sum of the lengths of the arcs in that path. The shortest path problem is to determine a directed path from node *s* to node *t* with the shortest total length. The *k*-shortest paths problem considered in WebShipCost can be described as follows: Given a directed network $G = (N, A)$, a distinguished source node *s* and a destination node *t*, and a set of arc lengths $c_{ij}(c_{ij} \geq 0)$, find the first, second,.., *k*th shortest paths from *s* to *t*, for any user-specified value of $k \in 1,2,...$.

As previously mentioned, there are many uncertain elements in 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 primary objectives have been identified in the influence diagram, i.e. cost, time, and reliability. Since the reliability objective is not as significant in containerized transportation, we will focus on the cost and time related uncertain elements and objectives here.

3.2.1 Cost Objective

In the previous section, the elements that may influence the transit cost are identified in the influence diagram. In a realistic intermodal transportation network that takes into account uncertainty, each arc should have an uncertain cost element. The cost of the arcs may be modeled as random variables. The distribution of the random variable may have a theoretical basis or may be empirically derived from historical data.

The notation used in the formulation is listed as follows:

- *G* – Define the directed network $G = (N, A)$, where $N = \{1,2,...,n\}$ is the node set, and $A = \{(i, j) \mid i, j \in N\}$ is the arc set;
- *s* – Let *s* denote the distinguished source node in the network *G*;
- *t* – Let *t* denote the distinguished destination node in the network *G*;

P – For a given pair of source s and destination t nodes, let $P = \{(i_0 = s, j_0), (i_1, j_1), (i_2, j_2), ..., (i_k, j_k = t)\}$ be the set of arcs that define the path where $j_{k-1} = i_k$, $k \in 1,2,...k$;

C_{ij} – For the cost objective, let C_{ij} be the random variable that represents the cost associated with arc (i, j); For a given path P, suppose C_{ij}, $(i, j) \in P$ are independent random variables;

C_P – Let C_P denote the total cost of the path P, i.e. $C_P = \sum_{(i,j) \in P} C_{ij}$;

$E(C_P)$ – Let $E(C_P)$ be the expected value of cost for path P;

$\sqrt{Var(C_P)}$ – Let $\sqrt{Var(C_P)}$ be the standard deviation of cost for path P;

p^* – Let p^* denote the path which the decision maker prefers;

C_u – 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.

For the cost objective, the decision maker would like to find the path that minimizes the expected total cost $E(C)$. In addition, decision makers will quite naturally want to control the risk associated with the problem. As such it could be natural to find the path that minimizes the standard deviation of the cost $\sqrt{Var(C)}$ and/or to find the path that minimizes the chance of exceeding an upper cost threshold $\Pr(C < C_u)$. Therefore three subobjectives 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 is within the decision makers' acceptable threshold.

Since we assume each arc is associated with a random variable representing uncertain cost, we obtain values for the three subobjectives through Monte Carlo simulation. After we have obtained deterministically optimal path candidates, the Monte Carlo simulation method is used to simulate the uncertainty and provide three subobjective values for each path, i.e. the mean value of the total cost, the standard deviation of cost, and $\Pr(C < C_u)$. The procedure of this method is listed as follows:

1. Specify the number of iterations n;
   let k represent the current iteration, set $k = 1$;
   let m represent the number of iterations during which the cost threshold goal is met, set $m = 0$;

2. Generate a random variate for each arc of the route from the distribution defined by historical data;
   compute the total cost of current route C_k;
   compare C_k and C_u, if $C_k < C_u$, $m = m + 1$;
   $k = k + 1$;

3. If $k = n$, stop;
   Otherwise, return to Step 2;

4. Compute mean value of total cost $\overline{C} = \frac{\sum_{k=1}^{n} C_k}{n}$;

   the standard deviation of total cost $\sqrt{Var(C)} = \sqrt{\frac{\sum_{k=1}^{n}\left(C_k - \overline{C}\right)^2}{n-1}}$; and

   the probability $\Pr(C < C_u) = \frac{m}{n}$.

3.2.2 Time Objective

The time objective includes three subobjectives similar to the cost subobjectives, i.e. the mean total time, the standard deviation of total time, and the probability of being within a time threshold. In addition, another subobjective that we want to consider is the probability of being within a particular time span. There are many realistic situations where this subobjective applies. For example, suppose the decision maker is a supervisor of a parts plant where Just In Time (JIT) is implemented. Therefore he wants his material resources from suppliers to arrive just in time, no sooner and no later, and he can only afford a certain amount of deviation from this expected time point. In this situation, this decision maker is primarily interested in the time span subobjective.

Time related notation is given below:

T_{ij} – For the time objective, let T_{ij} represent the transportation time associated with the transportation activities with arc $(i, j) \in A$. For a given path *P*, suppose T_{ij}, $(i, j) \in P$ are independent random variables;

T_P – Let T_P denote the total time associated with the transportation activities of the path *P*, i.e. $T_P = \sum_{(i,j) \in P} T_{ij}$;

$E(T_P)$ – Let $E(T_P)$ be the expected value of cost for path *P*;

$\sqrt{Var(T_P)}$ – Let $\sqrt{Var(T_P)}$ be the standard deviation of cost for path *P*;

T_u – Let T_u be an upper time threshold specified by the user for this decision problem. The upper time threshold represents the longest time for the path that the decision maker is willing to accept;

T_l – Let T_l be the lower bound of the time span;

T_h – Let T_h be the upper bound of the time span;

In this situation, we want to minimize the mean value $E(T)$ and standard deviation of the total transportation time $\sqrt{Var(T)}$, while at the same time, maximizing the probability that total transportation time is within time threshold $\Pr(T < T_u)$ and the probability that goods arrive within a preferred time span $\Pr(T_l < T < T_h)$.

Monte Carlo simulation is also performed here to evaluate these performance metrics of a predetermined route. The computation procedure is similar to that of the cost objective.

3.3 Analytic Hierarchy Process

Now that the problem has been formulated, the next issue is how to handle the multiple performance measures. The Analytic Hierarchy Process (Saaty, 1980) 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 the AHP to solve the path alternative decision problem consists of five stages (Canada et al., 1996).

- Decision hierarchy construction;
- Attribute priority determination;
- Alternative weight determination;
- Consistency computation, and
- Overall weighted performance determination.

In the remainder of this section, we will show the detailed procedure of applying AHP methodology to this decision problem.

3.3.1 Decision Hierarchy Construction

The first step is to construct the decision hierarchy. The hierarchy structure is presented in Figure 3-2. The top level of the hierarchy diagram refers to the overall goal of choosing the best path from the alternative path set. We will discuss how to generate the alternative path set in Section 3.3.6. The second level contains the three objectives for path evaluation: cost, time, and reliability. Each of these can be decomposed into subobjectives as shown in the third level of the decision hierarchy. At the bottom are the *k* path alternatives from which the decision maker must choose the most preferred.

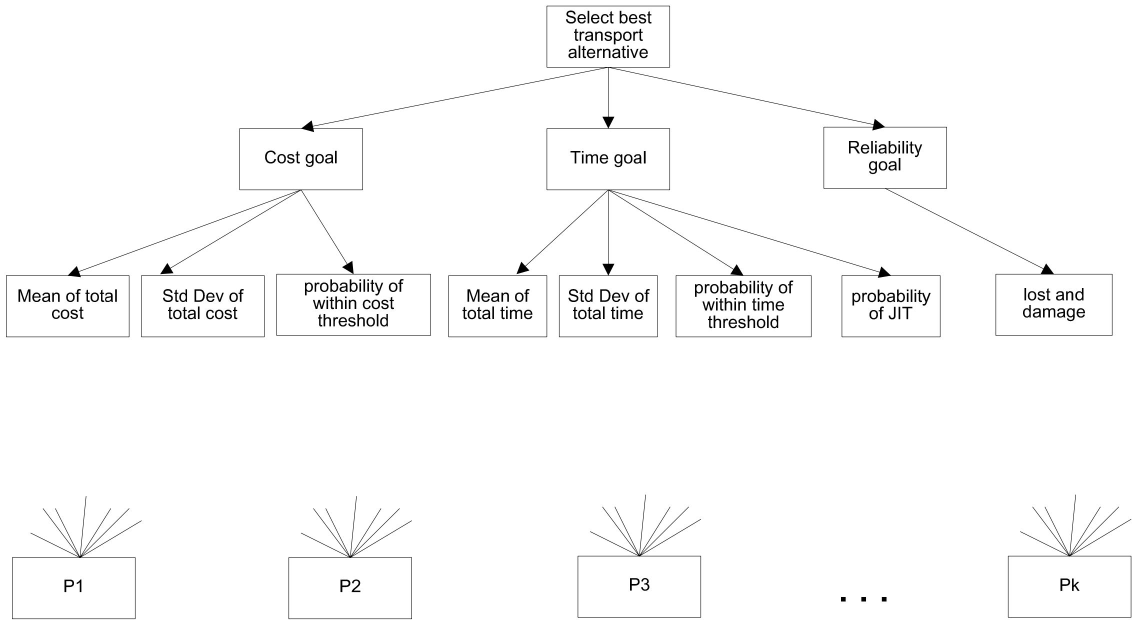


Figure 3-2 Decision Hierarchy

3.3.2 Attribute Priority Determination

Once the hierarchy is established, priorities should be established for each set of elements at every level of the hierarchy. The user of WebShipCost-Risk must be asked to evaluate a set of elements at one hierarchy level in a pairwise fashion regarding the relative importance with respect to each of the elements at the next higher level of the hierarchy. For example, the priority weights of the cost objective, time objective, and reliability objective in Table 3-1 were set to be equally important. Actual priority weight are set by the decision maker.

Table 3-1 Priority Weight

<table>
<tr><th>Objective (2nd level)</th><th>Priority Weight</th><th>Objective (3rd level)</th><th>Priority Weight</th></tr>
<tr><td rowspan="3">Cost objective (A)</td><td rowspan="3">0.33</td><td>Mean of total cost (A1)</td><td>0.33</td></tr>
<tr><td>Std Dev of total cost (A2)</td><td>0.33</td></tr>
<tr><td>Probability of within cost threshold (A3)</td><td>0.33</td></tr>
<tr><td rowspan="4">Time objective (B)</td><td rowspan="4">0.33</td><td>Mean of total time (B1)</td><td>0.25</td></tr>
<tr><td>Std Dev of total time (B2)</td><td>0.25</td></tr>
<tr><td>Probability of within time threshold (B3)</td><td>0.25</td></tr>
<tr><td>Probability of JIT (B4)</td><td>0.25</td></tr>
<tr><td>Reliability objective (C)</td><td>0.33</td><td colspan="2">N/A</td></tr>
</table>

3.3.3 Alternative Weight Determination

The next step is to determine the priority of each of the alternatives with respect to each of the attributes, i.e. the objective and subobjectives identified in the decision hierarchy. Typically, these priorities are also set using a pairwise comparison process. However because all of our performance data are quantifiable, we can directly convert our performance data to priority weight as described next.

When higher values of an alternative's performance on a particular attribute are "better", e.g. the probability of being within the cost threshold, the following single step normalization process is utilized.

$$W_j^{\,i} = \frac{d_j^{\,i}}{\sum_{i=1}^{k} d_j^{\,i}}$$

where

$W_j^{\,i}$ = the normalized priority weight of attribute *j* of path *i*

$d_j^{\,i}$ = the performance data value of attribute *j* of path *i*

k = the number of alternative paths

Conversely, when lower values are preferred such as total cost and total time, the following normalization process is used.

$$W_j^{\,i} = \frac{\min\left(d_j^{\,i}\right) / d_j^{\,i}}{\sum_{i=1}^{k} \left(\min\left(d_j^{\,i}\right) / d_j^{\,i} \right)}$$

where

$\min\left(d_j^{\,i}\right)$ = the minimal value of performance data for attribute *j* of all *k* alternatives

3.3.4 Consistency Computation

One of the strengths of AHP is its ability to measure the degree of consistency present in the subjective judgments made by the decision maker (Canada et al., 1996). Judgmental consistency is concerned with the transitivity of preference in the pairwise comparison matrices. It includes a local measure of consistency and global measure consistency. The local consistency ratio (C.R.) is an approximate mathematical indicator of the consistency of pairwise comparisons. Priority weights constructed directly from performance data always have perfect consistency.

3.3.5 Overall Weighted Performance Determination

The last step is the weighted performance determination for each alternative which is obtained by multiplying the matrix of evaluation ratings by the vector of priority weights and summing across all attributes. i.e.,

$$\text{Weighted performance for alternative } k = \sum_{all \text{ i attributes}} \left(\text{priority weight } t_i \times \text{ evaluation rating}\right)$$

The alternative with the highest weighted performance is the preferred alternative.

3.3.6 Overall Approach

The methodology for choosing the most desirable route in the intermodal transportation network is summarized as follows (notation is defined in Section 3.2):

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 $E(C_{ij})$. Since C_{ij} are 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 $P_c = \{p_{c1}, p_{c2},..., p_{ck}\}$;

Step 4. Decorate each arc with the expected time value $E(T_{ij})$. Also because of 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 $P_t = \{p_{t1}, p_{t2},..., p_{tk}\}$;

Step 6. Combine the path set P_c and P_t into a candidate path set P = $\{p_{c1}, p_{c2},..., p_{ck}, p_{t1}, p_{t2},..., p_{tk}\}$;

Step 7. Run Monte Carlo simulation on each path of path set P, compute the performance matrices;

Step 8. Use the AHP method to determine the final optimal path set ranked in the descending order of the overall weighted evaluation.

Figure 3-3 presents a diagram of this approach.

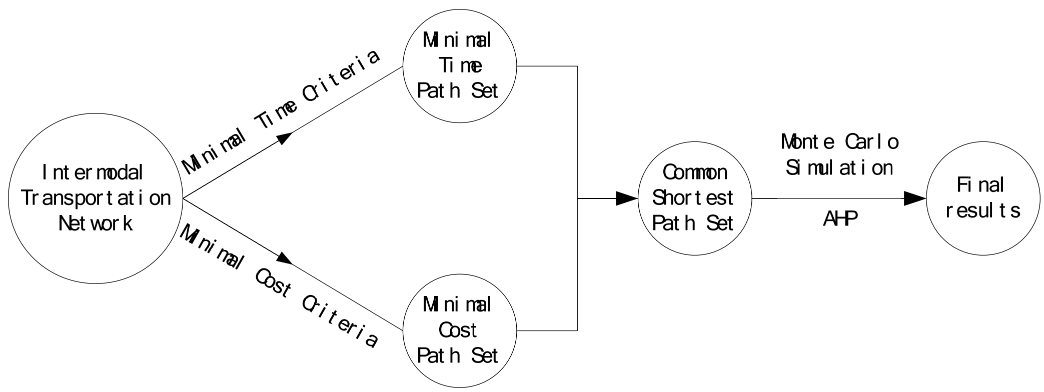


Figure 3-3 Methodology Diagram

3.4 Data Assumption and Optimal Path Set Evaluation

As stated in the problem formulation and AHP sections, the uncertain elements in the intermodal transportation decision model are represented by random variables. In general, there are two ways to obtain the distribution information for these variables. The first way is to empirically fit the data to random variables. The second is to assume reasonable theorized distributions to these variables. In this case, it is extremely difficult to obtain accurate historical data for the entire network. Therefore we make reasonable assumptions about these random variable distributions first. Then Monte Carlo simulation is used to evaluate the results of the optimal path set.

3.4.1 Data Assumption

The time and cost related uncertain elements are listed in Table 3-2, the random variables associated with these elements are assumed to be triangularly distributed, where the mode parameter equals the mean value identified by WebShipCost-Risk, the minimal boundary value equals 70% of the mode and the maximal boundary value is set as 130% of the mode.

Table 3-2 Time and Cost Related Uncertain Elements

Transportation Rates	Barge transportation rate – Inland barge transportation rate
	Rail transportation rate - Rail transportation rate per container-mile
	Long haul truck transportation rate per container-mile of each truck arc in the network
Drayage Costs	Truck-to-Barge drayage cost
	Truck-to-Rail drayage cost
Mode Speeds	Barge transportation speed
	Rail transportation speed
	Long haul truck transportation speed
Transfer Times and Costs	Barge/Rail transfer time and cost – The amount of time and associated cost of transferring containers from barge to rail or from rail to barge
	Barge/Truck transfer time and cost - The amount of time and associated cost of transferring containers from barge to truck or from truck to barge
	Truck/Rail transfer time and cost - The amount of time and associated cost of transferring containers from truck to rail or rail to truck

3.4.2 Optimal Path Set Evaluation

Since input data assumptions have been made, the network is ready for evaluation according to single objective. In this section, a thorough Monte Carlo simulation was performed based on the minimal cost objective and minimal time objective in order to evaluate the optimal path generated by the methodology described in the previous section. The procedure can be described as follows:

Step 1. Set the low level and high level of user input variables including order size, container capacity, item cost, holding cost rate, and the distance between origin and destination cities;

Step 2. Combine these user input variables; for distance, randomly pick up a pair of cities as origin and destination cities in the corresponding distance level;

Step 3. At each combination point, run the Monte Carlo simulation, get the shortest cost path and shortest time path;

Step 4. If maximum iteration number is reached, stop; otherwise return to Step 3.

In this problem, taking the simulation run time into consideration, the maximum iteration number is set to be 100. In each iteration, there are 32 experimental design points. The factor levels of user input variables are set based on general transportation knowledge as shown in Table 3-3. In regards to the distance between origin and destination cities variable, 665 miles is the median of the distance matrix for the network as shown in Appendix 7-2.

Table 3-3 Level Setting of User Input Variables

User Input Variables	**Low Level**	**High Level**
Distance between origin and destination cities	Less than 665 miles	More than 665 miles
Order size	1,000	5,000
Container capacity	100	500
Item cost	10	50
Holding cost rate	0.05	0.25

The simulation results for the minimal cost scenario are depicted in Table 3-4. From these results it is clear that barge transportation dominates the optimal path set when the objective is to minimize cost. This mode also comes with a longer total transport time span and a larger percentage of transport time. An interesting observation is that more than 40% of the total cost is attributed to the transfer activities.

Table 3-4 Descriptive Statistics of Shortest Cost Path Set (Minimal Cost)

Characteristic of Shortest Path Set	Mean	Standard Error
Percentage of dray cost	0.192	0.001
Percentage of transport cost	0.364	0.002
Percentage of transfer cost	0.402	0.002
Percentage of inventory holding cost	0.042	0.001
Percentage of transport time	0.948	0.001
Percentage of transfer time	0.052	0.001
Percentage of barge arcs	0.769	0.005
Percentage of truck arcs	0.040	0.002
Percentage of rail arcs	0.191	0.005
Percentage of barge distance	0.769	0.005
Percentage of truck distance	0.040	0.002
Percentage of rail distance	0.191	0.005
Total number of arcs	3.034	0.012
Total distance	1205.264	8.218
Number of barge arcs	2.496	0.020
Distance of barge arcs	1078.405	9.909
Total cost ($)	8121.836	107.981
Total time (hour)	192.570	1.690

Figures 3-4 through 3-6 are used to depict the relationships among the modes and cost activities.

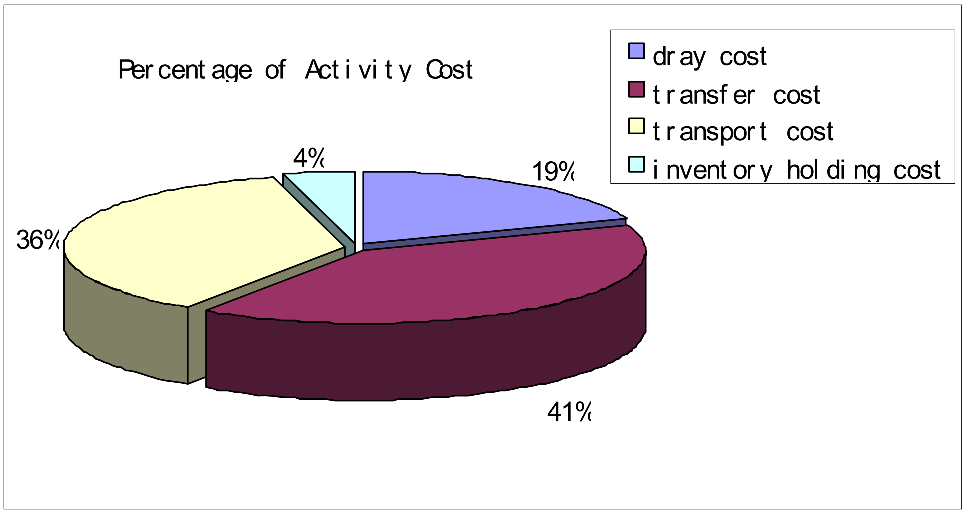


Figure 3-4 Percentage of Activity Cost (Minimal Cost)

As shown in Figure 3-4, transfer cost accounts for more than 40% of the total cost. There are two reasons for this dominance. First, as we can see in Figure 3-5 and 3-6, barge is the dominant mode in the optimal path considering the minimal cost objective. However drayage is performed by truck which caused more transfer activity. Second, transfer cost rate is higher for barge with other modes than the transfer rate between truck and rail. This further increases the transfer cost percentage.

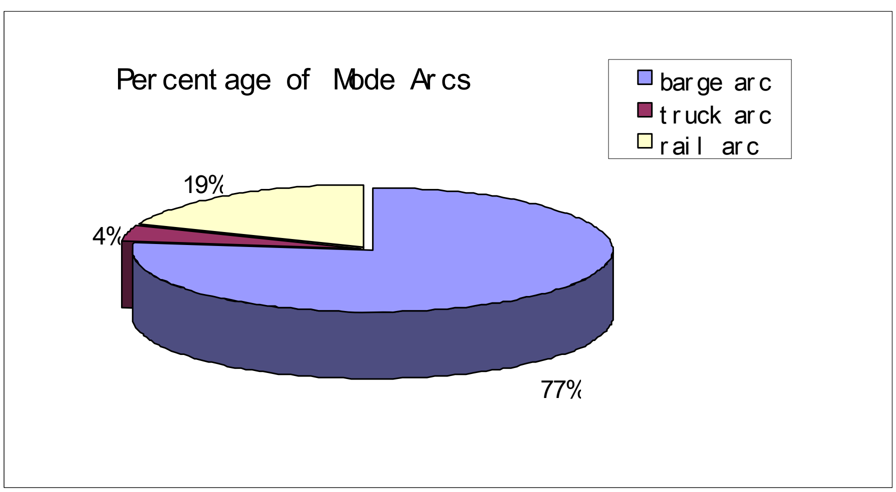


Figure 3-5 Percentage of Mode Arcs (Minimal Cost)

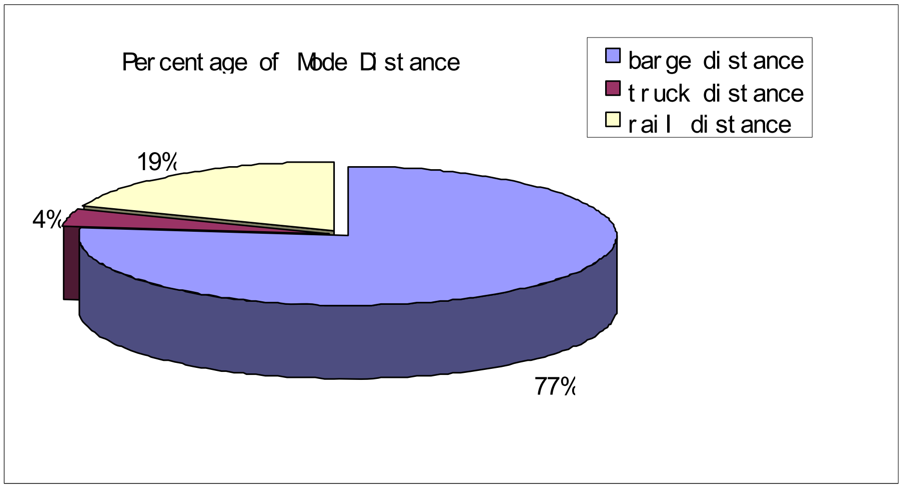


Figure 3-6 Percentage of Mode Distance (Minimal Cost)

The simulation results for the minimize time objective scenario are shown in Table 3-5.

Table 3-5 Descriptive Statistics of Shortest Cost Path Set (Minimal Time)

Characteristic of Shortest Path Set	Mean	Standard Error
Percentage of dray cost	0.023	0.001
Percentage of transport cost	0.934	0.002
Percentage of transfer cost	0.040	0.001
Percentage of inventory holding cost	0.003	0.000
Percentage of transport time	0.986	0.001
Percentage of transfer time	0.014	0.001
Percentage of barge arcs	0.000	0.000
Percentage of truck arcs	0.872	0.004
Percentage of rail arcs	0.128	0.004
Percentage of barge distance	0.000	0.000
Percentage of truck distance	0.879	0.004
Percentage of rail distance	0.121	0.004
Total number of arcs	2.773	0.010
Total distance	912.326	7.034
Number of barge arcs	0.000	0.000
Distance of barge arcs	0.000	0.000
Total cost ($)	22140.850	396.837
Total time (hour)	22.220	0.176

As shown in Table 3-5, when minimizing time is the objective, the truck mode dominates the shortest path set while the barge mode was never included in the optimal path. This is an expected result considering barge's significantly lower transport speed. Also, observed in Figure 3-7, more than 90% of total cost is attributed to transport activities since the transfer and dray cost are significantly reduced.

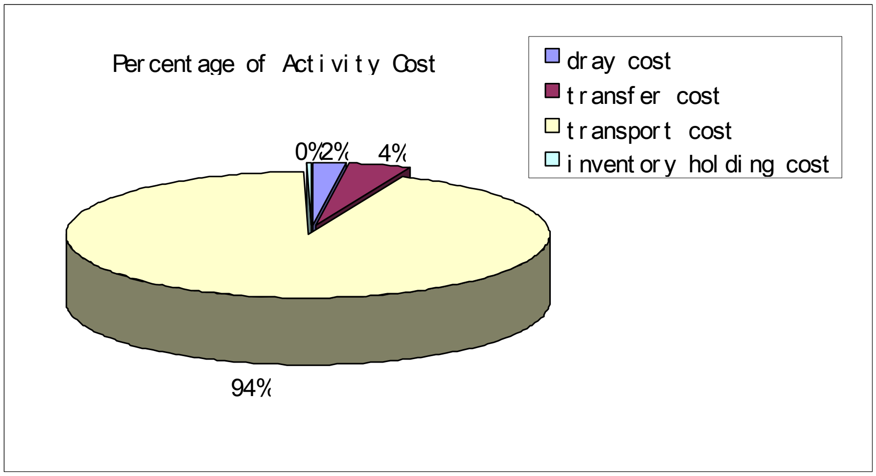


Figure 3-7 Percentage of Activity Cost (Minimal Time)

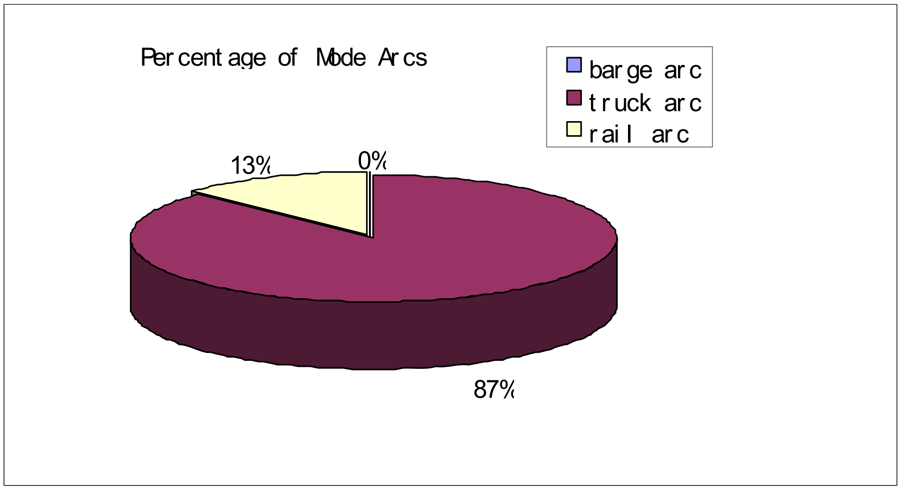


Figure 3-8 Percentage of Mode Arcs (Minimal Time)

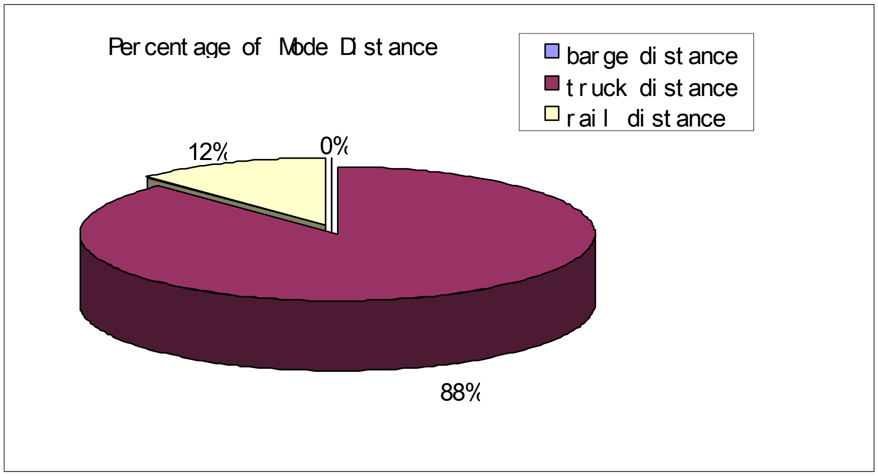


Figure 3-9 Percentage of Mode Distance (Minimal Time)

This section described the intermodal *k* shortest path problem as a multi-criteria decision problem under uncertainty. Uncertainty formulation and the application of the AHP to build the multi-objective decision model were discussed. The uncertain data assumptions were also discussed. Finally the optimal path sets were evaluated through Monte Carlo simulation. In the next section a thorough sensitivity analysis is performed to evaluate the effects of the experimental factors on the optimal path set.

4 SENSITIVITY ANALYSIS

In the previous section we formulated the uncertain elements, multi-objective model and a methodology to guide shippers in choosing the most desirable transportation route. In the current model, there are many factors that might affect the rankings of preferable routes: What influence do these factors have on the decision results? Under what conditions could the barge mode demonstrate superiority over the other modes? These questions can be addressed with a thorough sensitivity analysis using experimental design methods. In this section, we will discuss the design of experiments and the sensitivity analysis for the intermodal transportation decision problem.

4.1 Experiment Design

In our experimental design, several basic issues have to be examined initially – input variables (factors), their corresponding level identification, and response identification. Based on the analysis presented in the previous section, nine factors were identified and listed in Table 4-1. The experiment was conducted using a two level full factorial design investigating nine factors which are based on the general transportation knowledge. Table 4-1 also shows the setting of the factors in one scenario of the experiments.

Table 4-1 Factors of DOE

	Factor	Low	High
A	Weight of the cost, time, reliability objective	0.2, 0.4, 0.4	0.6, 0.2, 0.2
B	Cost threshold, threshold = (1 + B) * optimal value	0.5	1.0
C	Time threshold, threshold = (1 + C) * optimal value	0.5	1.0
D	Time lower & upper bound, Time lower bound = (1-D) * optimal value; Time upper bound = (1+D) * optimal value	0.2	0.5
E	Distance between origin and destination cities	<= 665 miles	> 665 miles
F	Order size	1,000	5,000
G	Container capacity	100	500
H	Item cost	$10	$50
I	Holding cost rate	0.05	0.25

As shown in Table 4-1, the weights of the cost/ time/ reliability objectives are defined as one single factor. Since the summation of these three parameters must equal 1, they are not independent. Suppose the shipper is primarily interested in one of the three objectives, three separate scenarios (cost, time, and reliability) can be defined where the weight of corresponding objective is specified and the weight of the other two are assumed to be equal. For example, in the cost scenario as shown in Table 4-1, shippers view the cost as the most important factor, the low and high value of weight of cost is set as 0.2 and 0.6. Then the weights of time and reliability are equally specified as $(1-0.2)/2 = 0.4$ and $(1-0.6)/2 = 0.2$ correspondingly;

The value or range of the preferred thresholds are also identified as factors. There are four such values: cost threshold, time threshold, time lower bound and time upper bound. We choose these values as the percentage of the corresponding value of the optimal path in the candidate path set. In other words, the optimal value for each objective in the candidate path is set to be the reference value. Based on this value, the decision maker set the preferred threshold value, expressed in percentage form.

Distance between origin and destination cities is the next factor. According to the distance matrix of the network (see Appendix 7.2), the distances are grouped into two categories: under 665 miles and beyond 665 miles where 665 is the median of truck distances among all network cities. The origin-destination pair among the category is randomly chosen based on a generated random number when the path selection scenario is specified.

Other user input variables, such as order size, container capacity, item cost, and holding cost rate are also identified as factors.

In order to evaluate the influence of the model factors on the decision results, the following three responses were 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.

4.2 Result Analysis

In this section, we discuss the evaluation results and conclusions, perform further experiments, and explore under which circumstances does the barge mode demonstrate advantages.

Considering the cost scenario of the experiment shown in Table 4-1, the shipper is primarily interested in the cost objective. The variation of cost weight, which is from 0.2 to 0.6, is higher than that of the time and reliability weights. The main effects plot for barge arcs in this case is shown in Figure 4-1.

A main effects plot is a plot of means at each level of a factor. It can be used to compare the magnitudes of the various main effects. A main effect occurs when the mean response changes across the levels of a factor. As shown in Figure 4-1, the X-axis gives the name of nine factors (from A to I as defined in Table 4-1). Each factor changes from the low value to the high value as shown on the top of the figure. The Y-axis marks the value of the response variable, which is, in this example, the number of barge arcs in the optimal path. As we can see, the weight of cost has the largest effect on the number of barge arcs. The detailed discussion of the effect of each factor on the response variable is shown in Table 4-2.

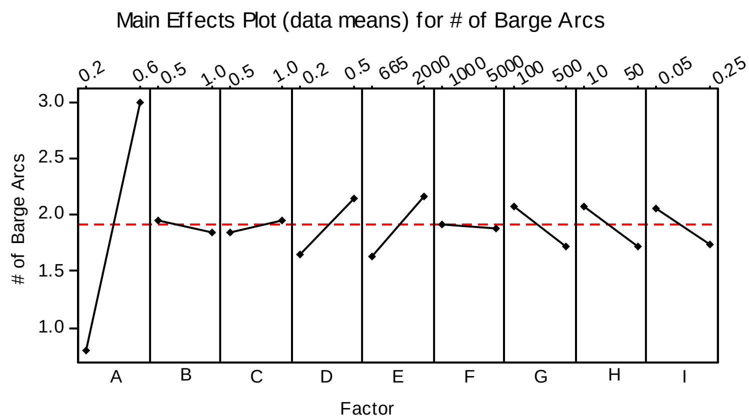


Figure 4-1 Main Effect Plot for Barge Arcs (Cost Scenario)

Table 4-2 Main Effect Plot Interpretation

Factor		Interpretation
A	Weight of the cost	The weight of cost has a large impact on the number of barge arcs. When the weight of cost increases, the barge mode becomes the dominant mode in the optimal path because of its much lower shipping rate compared with truck and rail.
B	Cost threshold, threshold = (1 + B) * optimal value	This factor is insignificant. This might be caused by the cost factor which is so significant.
C	Time threshold, threshold = (1 + C) * optimal value	When the time threshold becomes more relaxed, more barge arcs enter the optimal path. This seems reasonable because the transport time for barge is longer and has larger variations within the total transport time.
D	Time lower & upper bound, Time lower bound = (1-D) * optimal value; Time upper bound = (1+D) * optimal value	Like the time threshold, time lower & upper bound is another time constraint. When this constraint relaxes, more barge arcs enter the optimal path set.
E	Distance between origin and destination cities	When the distance between origin and destination increases, barge arcs in the optimal path increase. This indicates that because of the much lower transport cost, the gain of the barge mode becomes significant when the goods need to be shipped through a long path.
F	Order size	Order size is insignificant.
G	Container capacity	When container capacity increases, the same amount of goods can be handled by fewer containers. Thus the percentage incurred by the transport component of the total cost decreases which causes the benefit of barge mode to be not as significant as before.
H	Item cost	When more valuable items are shipped, the inventory holding cost became a significant part of the total transport cost. Since barge is much slower than truck and rail which comes with a much high inventory holding cost, the barge mode becomes less attractive and the number of barge arcs in the optimal path decreases.
I	Holding cost rate	Same as the factor item cost, when the holding cost rate increases, the mode barge becomes less attractive because of its much longer total transport time which causes a higher inventory holding cost.

After repeating the analysis for barge arc percentage and barge distance percentage, they are found to be similar to the results shown in Figure 4.1. In other words, these nine factors have similar effects on these two response variables – barge arc percentage and barge distance percentage.

In a similar way, experiments based on different cost, time, and reliability setting were also performed, the settings are listed in Table 4-3.

Table 4-3 Experiment Settings

Experiment	Weight of cost/ time/ reliability	
	Level 1	Level 2
1	0.2, 0.4, 0.4	0.6, 0.2, 0.2
2	0.4, 0.2, 0.4	0.2, 0.6, 0.2
3	0.2, 0.4, 0.4	0.8, 0.1, 0.1
4	0.4, 0.2, 0.4	0.1, 0.8, 0.1

In the AHP model presented previously, the time and cost weight are set by the user. The setting of weight has a direct influence on the resulting most preferable path. Here we study the effect of choosing the time and cost weight on the responses such as arc and distance percentage of each mode type in the resulting path, percentage of each cost and time element in the resulting path, etc. as defined in Section 4.1.

In Figures 4-2 and 4-3, mode arc percentage are plotted versus time and cost weights respectively. In these two figures, the X-axis denotes the time and cost weight while Y-axis is the mode arc percentage value. As we can see, the weight of time and cost have large effects on the mode choice. According to Figure 4-2, as the weight associated with the time objective increases (cost weight decreases), the truck mode becomes so dominant that it drives the other two modes out. The same thing happens when the time weight is at lowest point (cost weight at highest point), the barge mode is the dominant mode. Interestingly, the mode truck plays a part even when the weight of time or cost are not highly important considerations.

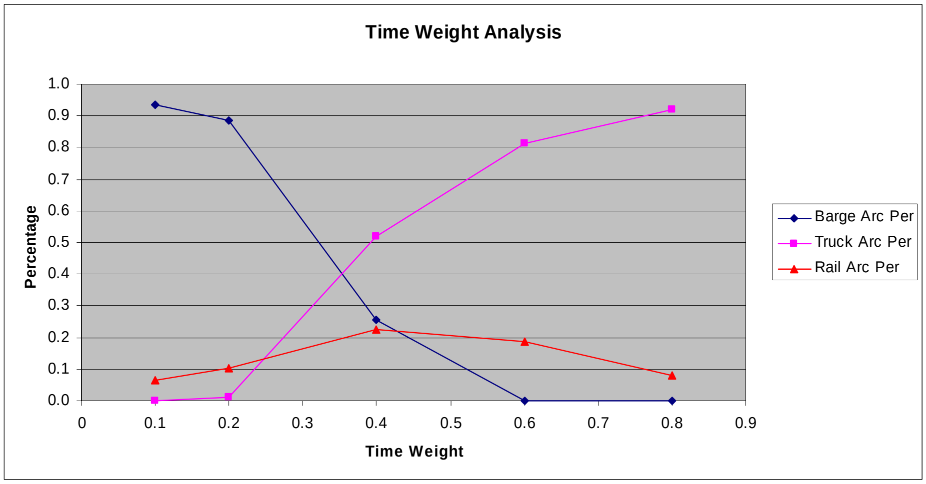


Figure 4-2 Mode Arc Percentage VS Time Weight

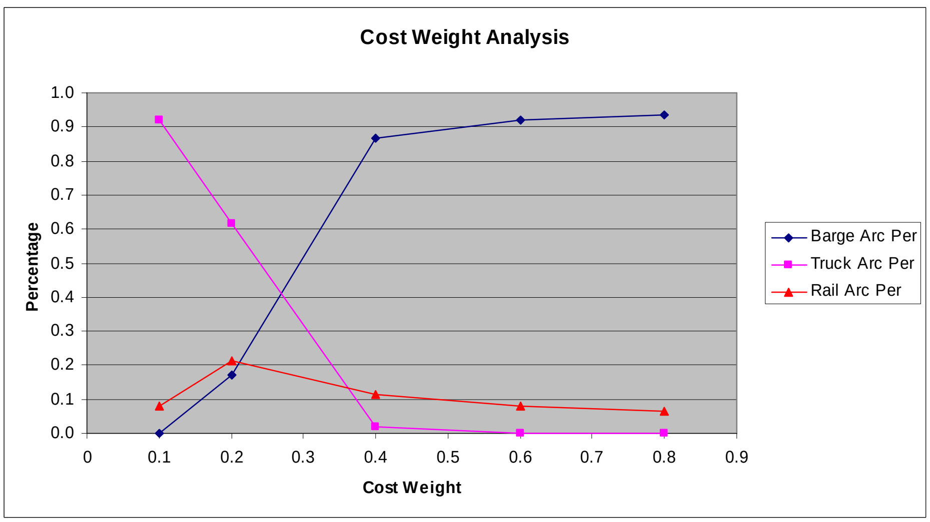


Figure 4-3 Mode Arc Percentage VS Cost Weight

Figure 4-4 and 4-5 show the relationships of total mean cost and mean time with time weight. In Figure 4-4, as time becomes a more important consideration, total mean cost increases. In Figure 4-5, as the time weight increases, the total mean time decreases. These two figures can easily be interpreted since as time weight increases, the barge mode is less prevalent in the optimal path set gradually while the more expensive but less-time-consuming truck mode increasingly appears in the path set.

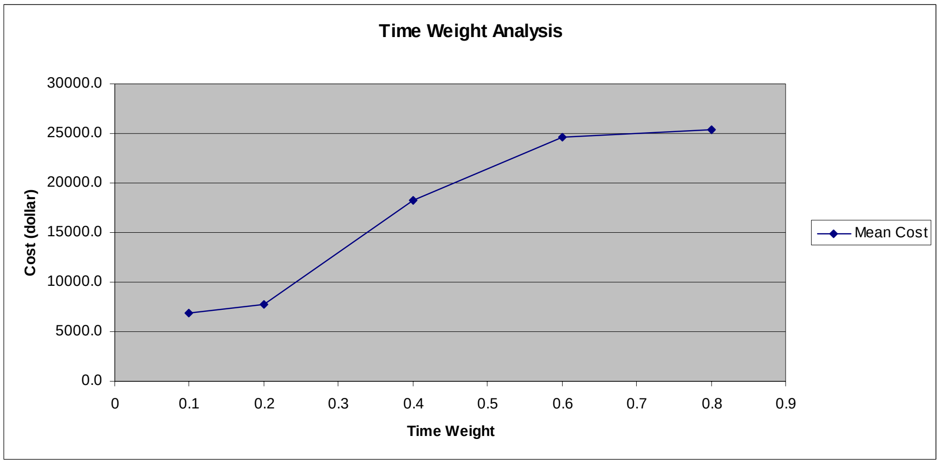


Figure 4-4 Mean Cost VS Time Weight

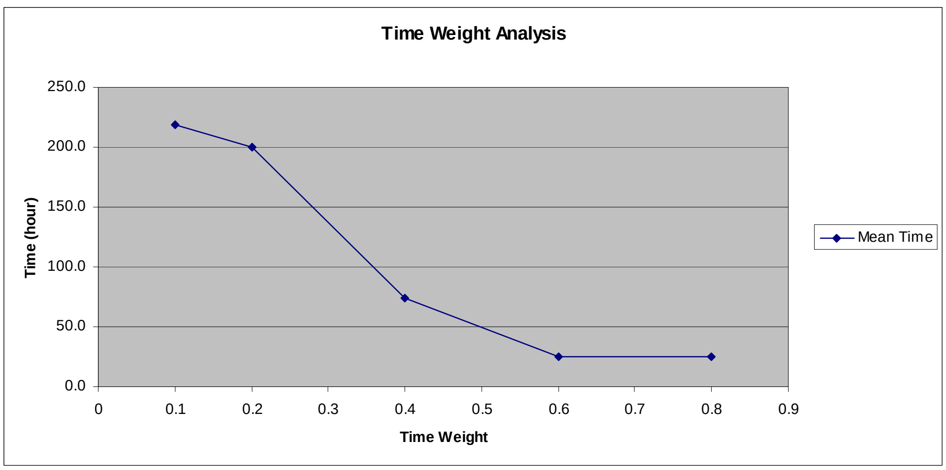


Figure 4-5 Mean Time VS Time Weight

In a similar way we plot the relationships of total mean cost and mean time with cost weight in Figure 4-6 and 4-7. In Figure 4-6, as cost becomes more important, total mean cost decreases. In Figure 4-5, as the cost weight increases, the total mean time increases. These two figures can be interpreted in a similar way as well. Since as cost weight increases, the barge mode is more prevalent in the optimal path set gradually while truck mode gradually disappears in the path set.

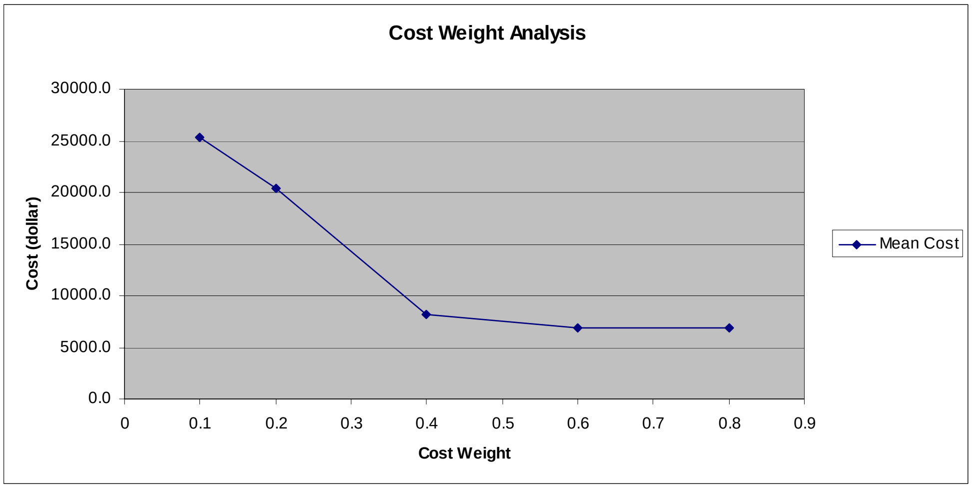


Figure 4-6 Mean Cost VS Cost Weight

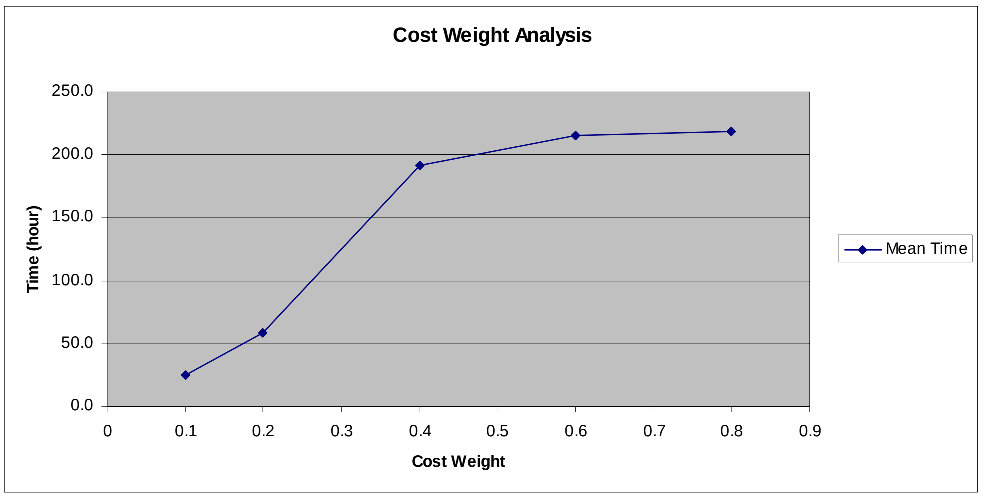


Figure 4-7 Mean Time VS Cost Weight

The relationships of cost and cost percentage for each transportation activities to the time and cost weights is the next consideration. As shown in Figures 4-8, 4-9, 4-10, and 4-11, cost and cost percentage have similar patterns. As the time weight increases, the transport cost becomes the dominant part of the total transportation cost while the other activity costs become insignificant. Another interesting thing is that at the point where time weight is 0.1, transfer cost is almost as much as transport cost. The sum of transfer cost and dray cost at this point is even greater than transport cost. This is caused by the high drayage and transfer cost rate. As shown in Figures 4-10 and 4-11, as cost weight increases, more intermodal activities emerge such as intermodal drayage, transferring, etc. which caused the percentage of transport cost to decrease significantly.

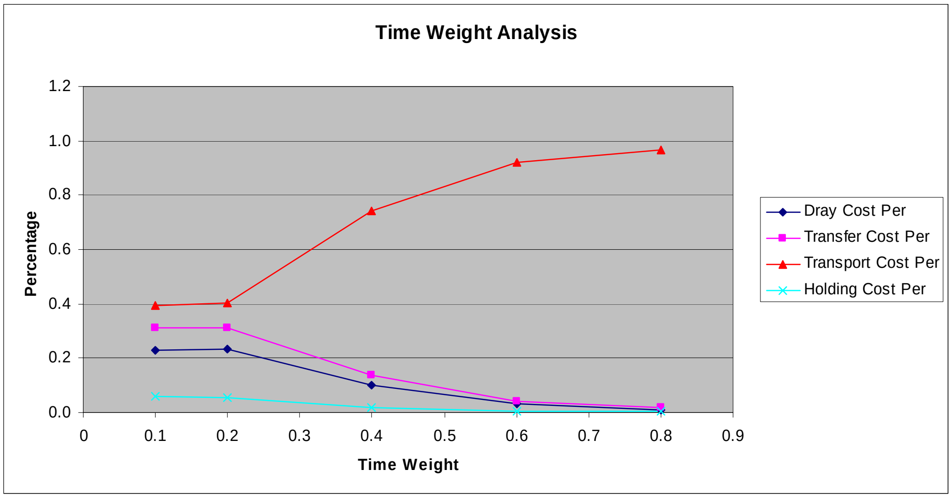


Figure 4-8 Cost Percentage VS Time Weight

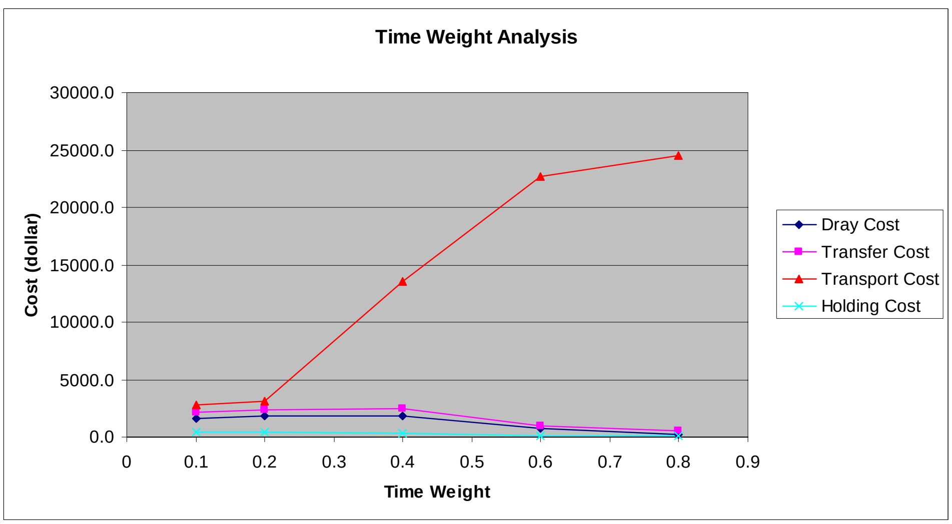


Figure 4-9 Cost VS Time Weight

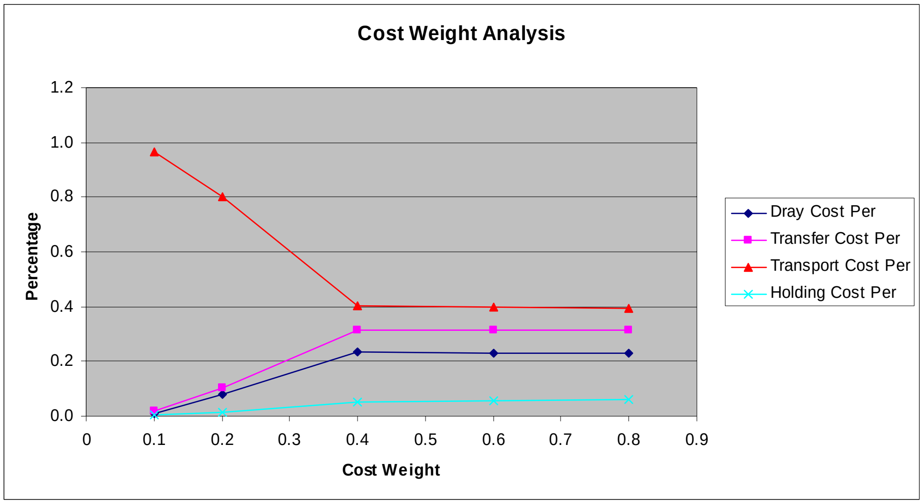


Figure 4-10 Cost Percentage VS Cost Weight

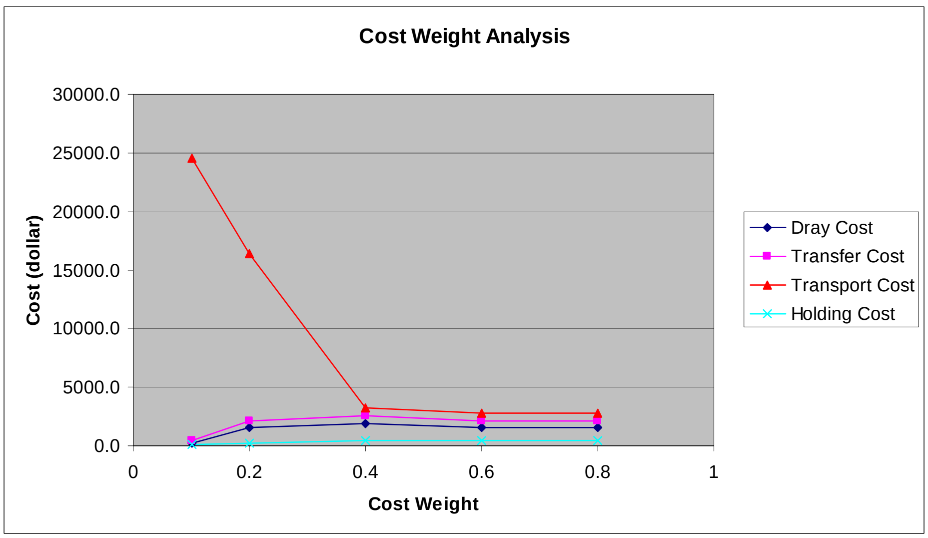


Figure 4-11 Cost VS Cost Weight

This section performed a thorough sensitivity analysis based on the experimental results. The mode barge plays a significant role in the current intermodal transportation network. In some cases, such as when the shipper considers minimum cost to be important, the barge becomes dominant in the most preferable route. The results also show that high drayage and transfer cost could be obstacles for barge to gain more superiority over truck and rail modes.

The WebShipCost – Risk application design and implementation issues are discussed in Section 5.

5 WEBSHIPCOST – RISK APPLICATION

In this section, we discuss the results of the software analysis, design, and implementation phases of the project. We first present a description of the use cases identified for the application.

5.1 Use Case Models

A use case is a statement of high-level functional system requirements in narrative text. Use cases serve as the basis for the software requirements and for setting the stage for the early identification of objects within the system. In addition, use cases serve as a basis for system test development. Use cases should emphasize top-level functions and interfaces based on the viewpoint of an actor. An actor is a well-defined role for a user or group of users. Actors can be people or they may be other systems with which the system interacts. Use cases begin at a high level and can be refined by subsystem all the way down to the object level. A use case model is the statement of use, use case diagram, use case description, and actor description.

The following presents the major actors of the WebShipCost - Risk system.

Actor Name: User

Description: A human user uses the WebShipCost – Risk system to compute the shortest paths between cities in a network and evaluate the associated risk elements. The user can also make changes to the user-related data in the database.

Actor Name: Database Manager

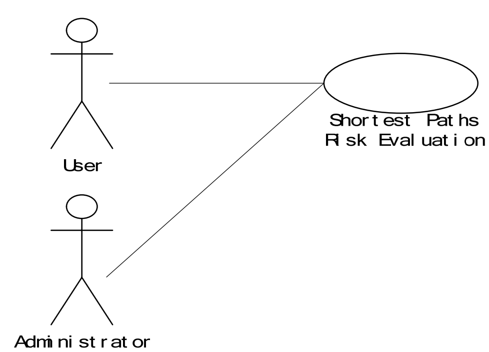
Description: A human user who takes the collected data and places it into the database. The database manager must have knowledge of the data set validation process and the database. The database manager can make changes to all of the data in the database.

Actor Name: Administrator

Description: A human user who has full control of the system – compute the shortest paths, evaluate the risks, perform sensitivity analysis and update the database. The administrator must have in-depth knowledge about the decision context and methodologies including the Analytic Hierarchy Process and design of experiments.

The following use case diagram identifies the "Shortest Paths Risk Evaluation" use case. A complete set of use cases and some important use case scenarios are listed in Appendix 7.3.

Table 5-1 "Shortest Paths Risk Evaluation" Use Case



Use case:	Shortest Paths Risk Evaluation
Section:	System level
Purpose:	To calculate the shortest paths and perform risk evaluation
Description:	User/administrator enters transportation information into the program and specifies the necessary parameters in order to get the shortest paths and the evaluation of risk performed by the program
Actors:	User, Administrator

5.2 Application Design

In order to reach the development goal of flexibility, reliability and efficiency, WebShipCost-Risk takes a strong object – orientation view of data structures and algorithms. The architecture of WebShipCost–Risk currently consists of five Java packages. Each package contains a set of interfaces and/or classes. They are grouped by related purpose and functionality. The current packages of the program are the following:

- wscrisk.graph: Package of graph building related interface and classes.
- wscrisk.algorithm: Package of shortest path algorithm related interface and classes.
- wscrisk.analysis: Package of interfaces and classes used for performing risk analysis and sensitivity analysis.
- wscrisk.comparator: Package of a variety of comparators used for sorting algorithms. The program handles the shortest path algorithm and these comparators sort the path list automatically according to different rules such as mean cost, mean time, and total weight (AHP), etc.
- wscrisk.util: This package contains some auxiliary classes providing functions such as database connection management, debugging output, etc.

For detailed information, readers can refer to Appendix 7.4.

6 SUMMARY

Prior MBTC WebShipCost research has been enhanced and has resulted in the development of WebShipCost-Risk, a risk-based multi-objective decision model for intermodal transportation networks which can help shippers make trade-offs among a variety of objectives and incorporate the uncertainty into the decision making process. In particular, the following results have been achieved:

- A review of the relevant literature in this area has been conducted.
- Key uncertain elements and risk-based performance measures associated with intermodal transportation have been identified;
- A multi-objective decision model has been built;
- A thorough sensitivity analysis based on experimental design methodology was performed to evaluate the influence of the model factors on the decision results;
- A user interaction model has been developed and implemented using a flexible web services approach.

Given the current architecture, WebShipCost-Risk is capable of performing risk analysis and multi-objective decision making.

For users of industry, analysis results are only as good as the data behind it. End users depend on current, accurate data to make correct decisions. Currently this analysis is based on data from research at University of Arkansas (Trusty and Malstrom, 1998) and the ShipCost user's manual (Boardman and Malstrom, 1998). The information is also derived from a detailed analysis performed for the Defense Logistics Agency [TLI-AR00-2]. The network is predefined. However, real, living, changing, evolving network information over time needs to be considered. How to keep data continuously updated is a challenging task for the current system.

A geographic information system (GIS) is computer software/system that links geographic information (where things are) with descriptive information (what things are). A GIS can present many layers of different information. All the transportation information— infrastructure information such as roadways, railroads, waterways, bridges and tunnels, transit place, and decision related information such as cost, transport speed, reliability, etc. —is stored as layers in digital format in the computer. The integration of WebShipCost with a GIS will provide the end user with more convenient and efficient data management methods to support the decision making in terms of route planning.

Future work will seek to:

- Expand WebShipCost to interactively accept user input transportation network data,
- Integrate WebShipCost with a Geographical Information System (GIS),
- Provide intermodal shippers with graphical and user-friendly information to improve decision making, and
- Test models and algorithms on problems associated with Arkansas waterway utilization.

Additional funding has been secured from the Mack Blackwell Transportation Center (MBTC 2047) to complete the future work discussed in this section.

7 APPENDICES

7.1 Transportation Network

Figure 7-1 Transportation Network (13 cities)

Table 7-1 City Location

City Name	Abbreviation	Location	River
Brownsville	Bro	Gulf Coast	Gulf Coast
Chicago	Chi	Midwest	Illinois
Cincinnati	Cin	Northeast	Ohio
Houston	Hou	Gulf Coast	Gulf Coast
Little Rock	LR	South	Arkansas
Memphis	Mem	Midwest	Mississippi
Mobile	Mob	Southeast	Alabama
New Orleans	NO	South	Mississippi
Omaha	Oma	Midwest	Missouri
Pittsburgh	Pit	Northeast	Ohio
St. Louis	SL	Midwest	Mississippi
St. Paul	SP	Midwest	Mississippi
Veracruz	Ver	Mexico/Central America	Ocean

7.2 Distance Matrix (Units: mile)

The distance matrix table shows the ground direct distances between each pair of cities. The length unit is miles.

Table 7-2 Distance Matrix

	Bro	Chi	Cin	Hou	LR	Mem	Mob	NO	Oma	Pit	SL	SP	Ver
Bro	0	1240	1180	295	685	680	660	530	1060	1420	980	1340	470
Chi	1240	0	250	945	550	490	780	840	430	410	260	340	1650
Cin	1180	250	0	890	530	405	615	700	615	260	310	590	1530
Hou	295	945	890	0	390	490	440	315	800	1150	690	1060	730
LR	685	550	530	390	0	130	380	360	490	790	300	710	1100
Mem	680	490	405	490	130	0	330	360	530	670	240	695	1160
Mob	660	780	615	440	380	330	0	140	350	810	560	1020	950
NO	530	840	700	315	360	360	140	0	850	920	600	1050	840
Oma	1060	430	615	800	490	530	350	850	0	840	355	300	1520
Pit	1420	410	260	1150	790	670	810	920	840	0	560	730	1750
SL	980	260	310	690	300	240	560	600	355	560	0	465	1380
SP	1340	340	590	1060	710	695	1020	1050	300	730	465	0	1790
Ver	470	1650	1530	730	1100	1160	950	840	1520	1750	1380	1790	0

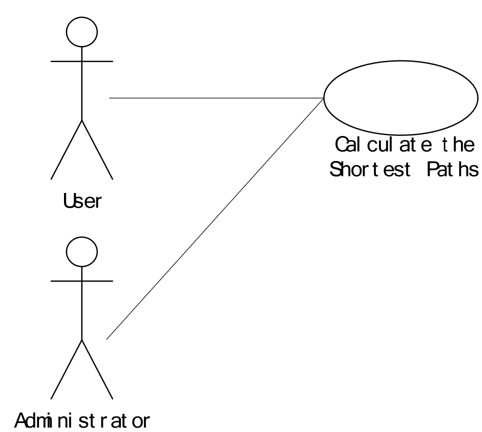
Table 7-3 Descriptive Statistics of Distances

Distances	
Mean	718.2051282
Median	665
Mode	530
Range	1660
Minimum	130
Maximum	1790
Count	78

7.3 Complete Use Case Models

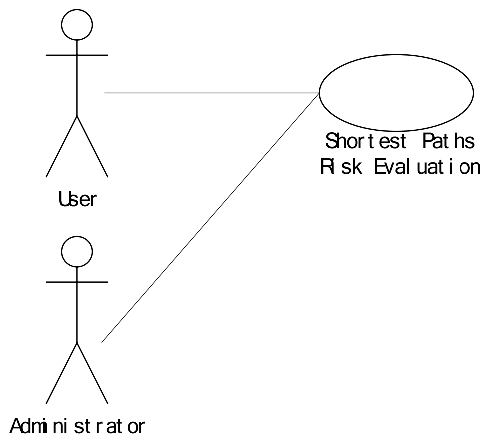
7.3.1 System Level:

"Calculate the Shortest Paths" Use Case



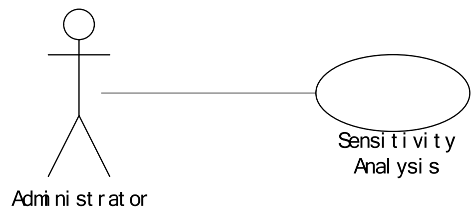
Use case:	Calculate the Shortest Paths
Section:	System level
Purpose:	To get the shortest paths between cities in a network
Description:	User/administrator enters transportation information such as shipping size, item cost, etc. into the program in order to get the shortest paths computed by the program
Actors:	User, Administrator

“Shortest Paths Risk Evaluation” Use Case



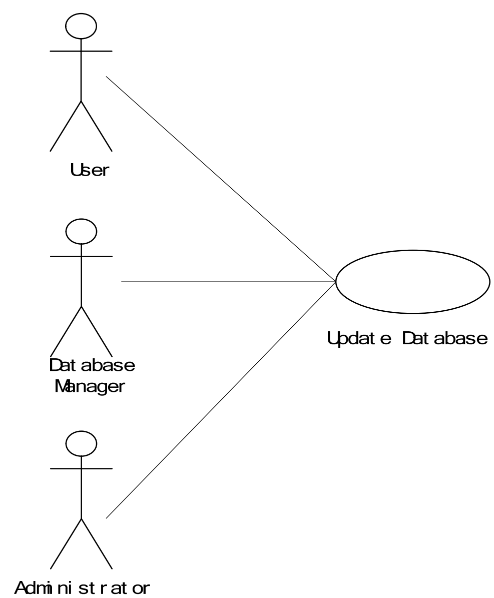
Use case:	Shortest Paths Risk Evaluation
Section:	System level
Purpose:	To calculate the shortest paths and perform risk evaluation
Description:	User/administrator enters transportation information into the program and specify the necessary parameters in order to get the shortest paths and the evaluation of risk performed by the program
Actors:	User, Administrator

“Sensitivity Analysis” Use Case



Use case:	Sensitivity Analysis
Section:	System level
Purpose:	To study the influence of transportation factors such as time and cost weight, cost threshold, etc. on the mode choice and explore the advantages of the barge mode
Description:	Administrator setups the experiment factors. The program performs the full experiment and presents the results
Actors:	Administrator

“Update Database” Use Case



Use case:	Update Database
Section:	System level
Purpose:	To keep the data in the database updated
Description:	User can change user related information in the database. Database manager and administrator have the privilege to update the data stored in all the tables. The database and tables are also created by database manager or administrator.
Actors:	User, Database Manager, Administrator

7.3.2 Subsystem Level:

“Input Transportation Information” Sub Use Case

Use case	Input Transportation Information
Upper level	Calculate the Shortest Paths
Purpose:	Input necessary transportation information into system in order to compute the shortest paths
Description:	Necessary information includes origin city, destination city, number of units to be shipped, number of units per container, unit price, percentage of the unit cost to be used in the carrying cost, objective (minimize time or cost) and the number of paths to be found

“View the Shortest Paths Results” Sub Use Case

Use case	View the Calculation Results
Upper level	Calculate the Shortest Paths
Purpose:	Show the computation results
Description:	User is provided with the computation results including all of the nodes of each path and mode information between each pair of nodes

“Specify Risk Evaluation Related Parameters” Sub Use Case

Use case	Specify Risk Evaluation Related Parameters
Upper level	Shortest Paths Risk Evaluation
Purpose:	Input transportation information and specify the risk evaluation related parameters into system
Description:	Transportation information includes origin city, destination city, number of units to be shipped, number of units per container, unit price, percentage of the unit cost to be used in the carrying cost and the number of paths to be found. Risk related parameters include priority weight of cost goal, priority weight of time goal, priority weight of reliability goal, upper bound of acceptable cost threshold, upper bound of acceptable time threshold, acceptable delivery time span

“View the Risk Evaluation Results” Sub Use Case

Use case	View the Risk Evaluation Results
Upper level	Shortest Paths Risk Evaluation
Purpose:	Show the evaluation results
Description:	User is provided with the computation results including all of the nodes of each path and mode of transportation between each pair of nodes and the risk evaluation, i.e. the overall priority weight of each path

“Setup Experiment Factors” Sub Use Case

Use case	Setup Experiment Factors
Upper level	Sensitivity Analysis
Purpose:	To setup the experiment factor levels
Description:	Administrator determines the factor levels in order to perform the sensitivity analysis. The factors include: priority weight of cost, acceptable cost threshold, acceptable time threshold, time lower & upper bound (i.e. acceptable delivery time span) , cost lower & upper bound, distance between origin and destination cities (divided in two groups: less than or equal to 665 miles and more than 665 miles), order size, container capacity, item cost and holding cost rate

“View the Experiment Results” Sub Use Case

Use case	View the Experiment Results
Upper level	Sensitivity Analysis
Purpose:	Show the sensitivity analysis results
Description:	The results include percentage of arcs of each mode in the resulting best path and distance percentage of each mode in the resulting best path

“Update the User Information” Sub Use Case

Use case	Update the User Information
Upper level	Update Database
Purpose:	To update information related to system user
Description:	User information includes user name, email address and user description.

“Update the Problem Information” Sub Use Case

Use case	Update the Problem Information
Upper level	Update Database
Purpose:	To update information related to problem
Description:	Problem information includes title, create date and description

“Update the Input Scenario Information” Sub Use Case

Use case	Update the Input Scenario Information
Upper level	Update Database
Purpose:	To update information related to input scenario
Description:	Input scenario information includes title and description

“Update the Network Information” Sub Use Case

Use case	Update the Network Information
Upper level	Update Database
Purpose:	To update information related to network
Description:	Network information includes network name, currency units, distance units and time units

“Update the Node Information” Sub Use Case

Use case	Update the Node Information
Upper level	Update Database
Purpose:	To update information related to node
Description:	Node information includes node name

“Update the City Information” Sub Use Case

Use case	Update the City Information
Upper level	Update Database
Purpose:	To update information related to city
Description:	City information includes city name

“Update the Specific Transfer Information” Sub Use Case

Use case	Update the Specific Transfer Information
Upper level	Update Database
Purpose:	To update information related to specific transfer time and rate
Description:	Specific Transfer information includes transfer cost rate and transfer time

“Update the Mode Information” Sub Use Case

Use case	Update the Mode Information
Upper level	Update Database
Purpose:	To update information related to mode
Description:	Mode information includes mode name, average mode transport speed, average cost rate, average dray cost rate and average carrying cost

“Update the Dray Cost Information” Sub Use Case

Use case	Update the Dray Cost Information
Upper level	Update Database
Purpose:	To update information related to dray cost information
Description:	Dray cost information includes cost rate

“Update the Transport Information” Sub Use Case

Use case	Update the Transport Information
Upper level	Update Database
Purpose:	To update information related to transport
Description:	Transport information includes transport cost rate, speed and distance between all pairs of origin and destination cities

“Update the Average Transfer Information” Sub Use Case

Use case	Update the Average Transfer Information
Upper level	Update Database
Purpose:	To update information related to average transfer
Description:	Average transfer information includes average transfer cost rate and average transfer time

7.3.3 Use Case Scenarios for Selected Use Cases:

This section includes detailed use case scenarios for a select group of use cases that are important and representative of the system.

Use Case: Input Transportation Information

Use Case Scenario for “Input Transportation Information”

	Actor Action	**System Response**
1	The use case begins when the actor clicks the “Shortest Path” tag on the homepage	
2		Displays the following items: 1. Source City(Dropdown menu) 2. Destination City(Dropdown menu) 3. Number of Units to be shipped(Textbox) 4. Number of Units per container(Textbox) 5. Cost of each unit to the producer(Textbox) 6. Percentage of the unit cost used n calculating Carrying Cost(Textbox) 7. Objective(Radio button) 8. Number of paths to be found(Textbox) 9. Options for “Calculate the Shortest Paths”(Button), “Reset”(Button) and “Home”(Link) are provided
3	User can enter values and click on “Calculate the Shortest Paths” button	
4		System checks the validation of the input information
5		If all values are valid, system should take user to the “Shortest Path List” page; otherwise ask the user to reenter the invalid values
6	User can click “Reset” button	
7		All values entered should be cleared
8	User can choose “Home” link	
9		System should display the homepage

Use Case: View the Shortest Paths Results

Use Case Scenario for "View the Shortest Paths Results"

	Actor Action	**System Response**
1	The use case begins when the actor clicks on "Calculate the Shortest Paths" button on the page "Shortest Path"	
2		Displays the following item: 1. Problem Scenario(Text) 2. Shortest paths list(Text) 3. Options for "Detail"(Button) and "Return"(Button) are provided
3	User can click "Detail" button	
4		System should display the path details such as all of the nodes of that path and mode information between each pair of them
5	User can click "Return" button	
6		System returns to the "Shortest Path" page

Use Case: Specify Risk Evaluation Related Parameters

Use Case Scenario for "Specify Risk Evaluation Related Parameters"

	Actor Action	**System Response**
1	The use case begins when the actor clicks the "Risk Evaluation" tag on the homepage	
2		Displays the following item: 1. Source City(Dropdown menu) 2. Destination City(Dropdown menu) 3. Number of Units to be shipped(Textbox) 4. Number of Units per container (Textbox) 5. Cost of each unit to the producer(Textbox) 6. Percentage of the unit cost used n calculating Carrying Cost(Textbox) 7. Number of paths to be found(Textbox) 8. Priority weight of cost goal(Textbox) 9. Priority weight of time goal(Textbox) 10. Priority weight of reliability goal(Textbox) 11. Options for "Value Bound" and "Percentage Bound"(Optional box) 12. Cost upper bound(Textbox) 13. Time upper bound(Textbox) 14. Delivery time span(Textbox) Options for "Run Evaluation"(Button), "Reset" (Button) and "Home" (Link) are provided
3	User can enter values and click on "Run Evaluation"	
4		System check the validation of the input information
5		If all values are valid, system should take user to the "Risk Evaluation Results" page; otherwise ask the user to reenter the invalid values
6	User can click "Reset" button	
7		All values entered should be cleared

8	User can choose “Home” link	
9		System should display the homepage

Use Case: View the Risk Evaluation Results

Use Case Scenario for “View the Risk Evaluation Results”

	Actor Action	**System Response**
1	The use case begins when the actor clicks on “Run Evaluation” button on the page “Risk Evaluation”	
2		Displays the following item: 1. Problem Scenario(Text) 2. Shortest paths list(Text) 3. Overall priority weight of each path(Text) 4. Options for “Detail”(Button) and “Return”(Button) are provided
3	User can click “Detail” button	
4		System should display the path details such as all of the nodes of that path and mode information between each pair of them
5	User can click “Return” button	
6		System returns to the “Risk Evaluation” page

Use Case: Setup Experiment Factors

Use Case Scenario for "Setup Experiment Factors"

	Actor Action	System Response
1	The use case begins when the actor clicks the "Sensitivity Analysis" tag on the homepage	
2		Displays the following items: 1. Options for scenario selection: "Cost", "Time" and "Reliability"(Optional box) 2. Weight, corresponding to the scenario selection(Textbox) 3. Cost threshold(Textbox) 4. Time threshold(Textbox) 5. Time lower & upper bound(Textbox) 6. Cost lower & upper bound(Textbox) 7. Distance between origin and destination cities: "less than 500 miles", "between 500 and 1000 miles" and "more than 1000 miles" (Optional box) 8. Order size(Textbox) 9. Container capacity(Textbox) 10. Item cost(Textbox) 11. Holding cost rate(Textbox) 12. Options for "Run Sensitivity Analysis", "Reset" and "Home" are provided
3	User can enter values and click on "Run Sensitivity Analysis"	
4		System checks the validity of the input information
5		If all values are valid, the system performs the analysis and takes the user to the "Experiment Results" page; otherwise asks the user to reenter the invalid values
6	User can click "Reset" button	
7		All values entered should be cleared
8	User can choose "Home" link	
9		System should display the homepage

Use Case: View the Experiment Results

Use Case Scenario for “View the Experiment Results”

	Actor Action	**System Response**
1	The use case begins when the actor clicks the “Run Sensitivity Analysis” button on the page “Sensitivity Analysis”	
2		Displays the following item: 1. Experiment Factors(Text) 2. Analysis results(Text) 3. “Return”(Button)
3	User can click “Return” button	
4		System returns to the “Sensitivity Analysis” page

Use Case: Update the Specific Transfer Information

Use Case Scenario for “Update the Specific Transfer Information”

	Actor Action	**System Response**
1	The use case begins when the user choses to update the Specific Transfer Information	
2		Displays the input boxes such as “Choose the city”, “Choose the From Mode”, “Choose the To Mode”, “Cost data” and “Setup time data”
3	The user inputs the new data into these input boxes	
4	The user clicks the submit button	
5		System checks the validity of the input data
6		If all values are valid, the system updates the database with the new data; otherwise asks the user to reenter the data
7	User can click “Cancel” button	

7.4 Application Design

As mentioned in Section 5, the architecture of WebShipCost–Risk consists of five Java packages. Each package contains a set of interfaces and/or classes.

- wscrisk.graph: Package of graph building related interface and classes.
- wscrisk.algorithm: Package of shortest path algorithm related interface and classes.
- wscrisk.analysis: Package of interfaces and classes used for performing risk analysis and sensitivity analysis.
- wscrisk.comparator: Package of a variety of comparators used for sorting algorithm.
- wscrisk.util: This package contains some auxiliary classes providing functions such as database connection management, debugging output, etc.

As the first three packages are the most important, we discuss them in detail.

7.4.1 Package wscrisk.graph

The purpose of the graph building package is to extract the information that is stored in the database and to build a proper intermodal graph representation for the shortest path algorithm. A graph is a set of vertices and arcs. Arcs are used to represent a linkage between two vertices. For the details of graph representation, please refer Rossetti & Nachtmann (2003). The package diagram is the following:

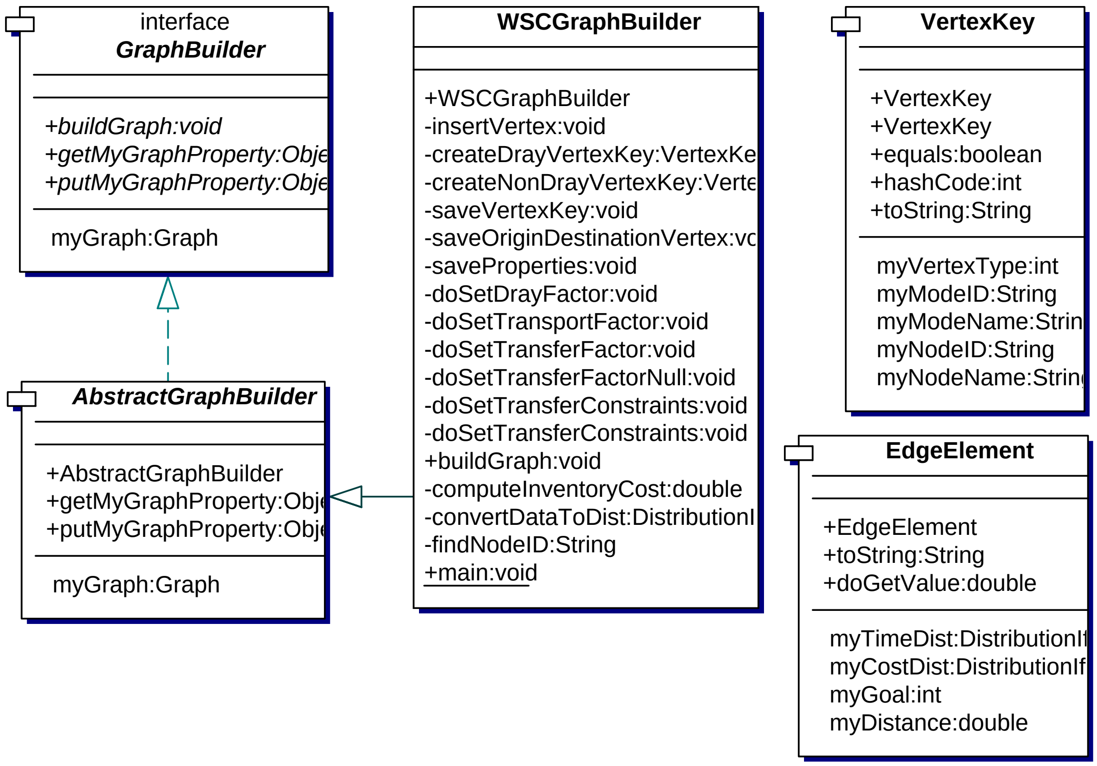


Figure 7-2 Class Diagram of Graph Package

In Interface **GraphBubilder** defines the behaviors of the classes responsible for graph construction. The four methods shown in Table 7-4 are the most important.

Table 7-4 Interface GraphBuilder Method Summary

Method Summary	
public void	**buildGraph**() build the graph, has to be implemented by sub class
public Graph	**getMyGraph**() return the graph, implemented by the abstract class
public Object	**getMyGraphProperty**(Object objKey) return a specific property object of the graph, the meaning of the properties are defined by the user; if the objKey is not defined, return null.
public Object	**putMyGraphProperty**(Object objKey, Object objValue) save the specific graph property into GraphBuilder's property map structure

For our specific problem, **WSCGraphBuilder** knows the WebShipCost – Risk database structure and is responsible for the intermodal transportation network construction. It extends from the abstract class **AbstractGraphBuilder** which implements the **GraphBuilder** interface.

Class VertexKey has two purposes. The first purpose is to hold the information associated with a specific vertex in the network. This is very useful during the graph construction process. The second function is to store all of the information about the vertex used to retrieve the path information at a later time. For example, in package analysis, class **WSCProblemSolver** uses this information to build the path representation. In addition to that, the vertex information is used during the AHP analysis.

There is one difference between the current program's graph and the graph used in the WebShipCost project. Since we incorporate the uncertain elements these elements must be stored in the graph. Class **EdgeElement** is used to hold the time and cost distribution for the arcs.

7.4.2 Package wscrisk.algorithm

This package contains the interfaces and classes that handle the shortest path solving problem. The following is the diagram:

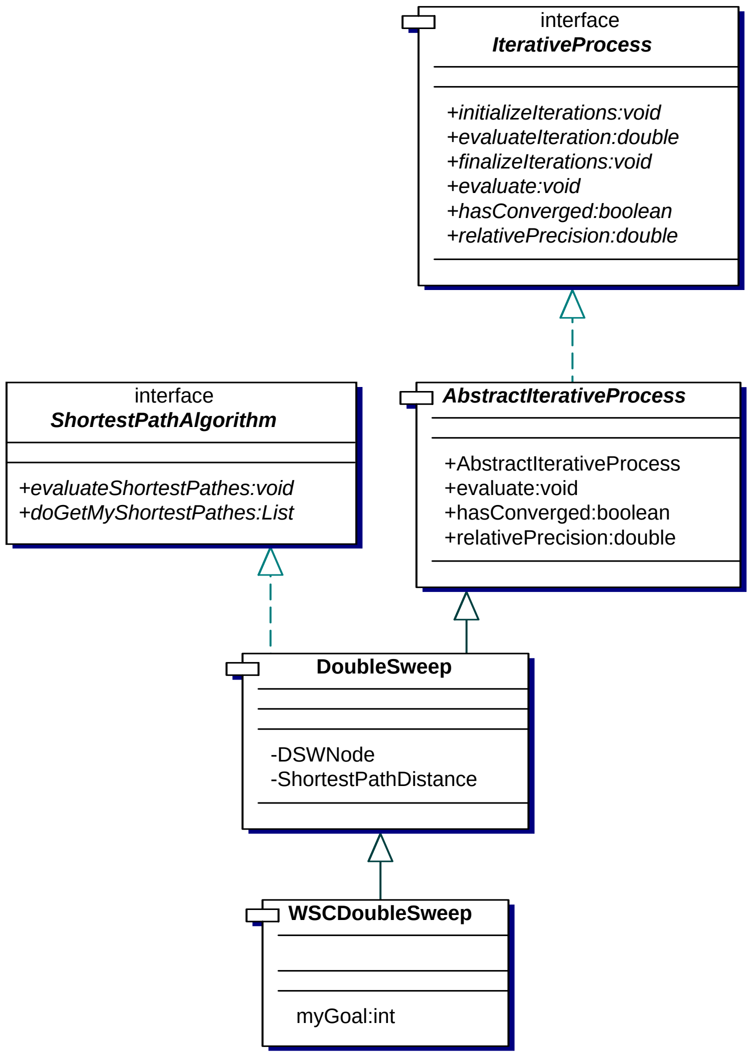


Figure 7-3 Class Diagram of Algorithm Package

Two main methods are defined by the interface **ShortestPathAlgorithm**, i.e. **doGetMyShortestPathes()** and **evaluateShortestPathes().** All of the shortest path algorithms should implement this interface. In this project, we implemented the double sweep algorithm developed by (Shier, 1974) in the class **DoubleSweep** to solve the *k* shortest path problem. The double sweep algorithm is an iterative process. Thus, another interface **IterativeProcess** is defined and class **DoubleSweep** also implements this interface. In fact, **DoubleSweep** extends the abstract class **AbstractIterativeProcess** since it implements some methods for progrommer convenience. Class **DoubleSweep** handles the general Graph object generated by the **GraphBuilder**. All of the specific problem related issues such as path representation and path evaluation are separated from the general algorithm. The method summary of these two interfaces and package diagram is given in Table 7-5.

Table 7-5 Interface ShortestPathAlgorithm Method Summary

Method Summary	
public List	**doGetMyShortestPathes**() return shortest paths
public void	**evaluateShortestPathes**() compute the shortest paths

7.4.3 Package wscrisk.analysis

This package contains key classes and interfaces for risk and sensitivity analysis. Figure 7-4 presents the class diagram:

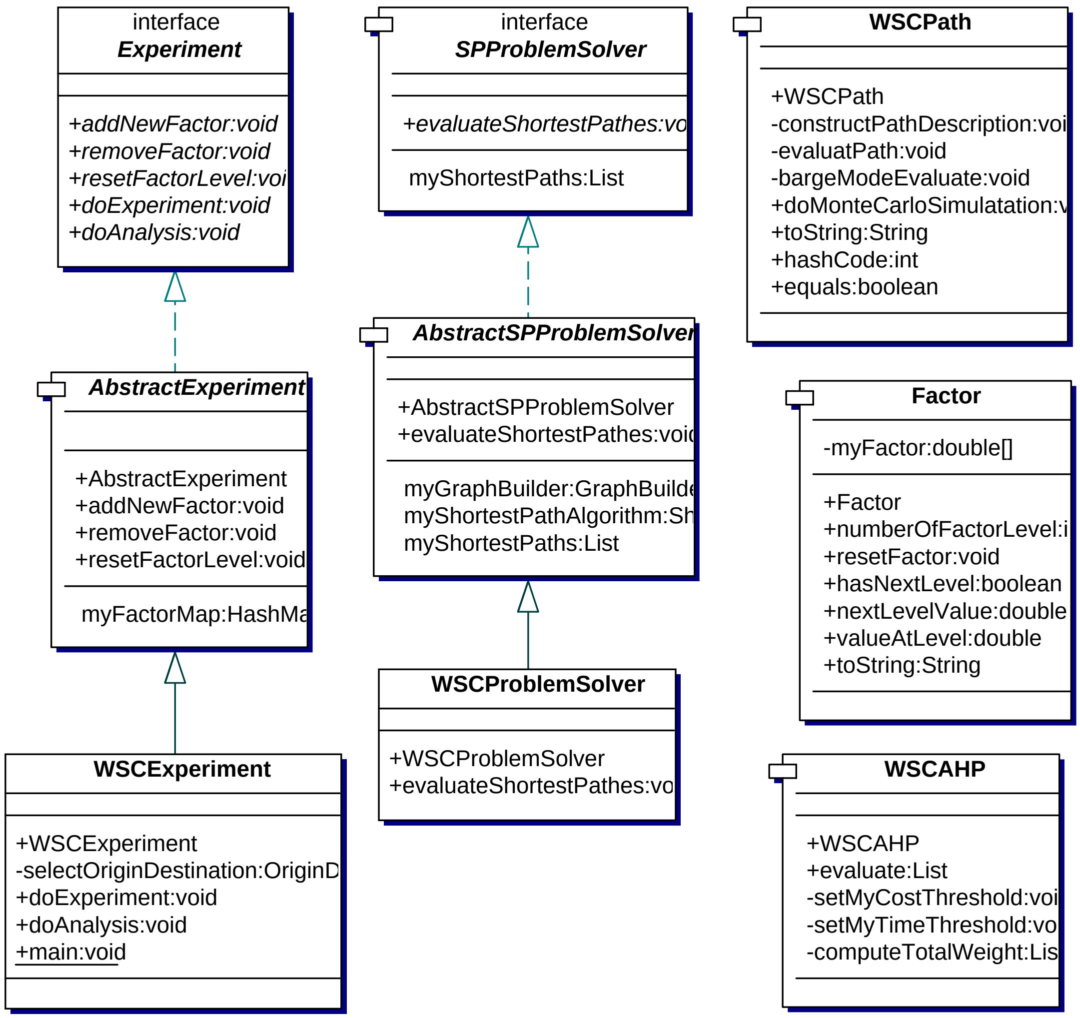


Figure 7-4 Class Diagram of Analysis Package

Interface **SPProblemSolver** takes GraphBuilder and ShortestPathAlgorithm as its input parameters. We encapsulate problem specific tasks into classes implemented this interface. For example, class WSCProblemSolver knows the WebShipCost–Risk problem context and does a series of tasks such as build the path description which is related to our specific transportation network. Here is the interface definition.

Table 7-6 Interface SPProblemSolver Method Summary

Method Summary	
public void	**evaluateShortestPathes**() construct the List of path objects
public List	**getMyShortestPaths**() return the list of path objects

Class **WSCPath** denotes the path object which is a fundamental element in this problem. One important method is **doMonteCarloSimulation().** In this method the Monte Carlo simulation is implemented to evaluate the variability of cost and time attributes of the path.

Another key class is **WSCAHP** which accepts a list of path objects and does AHP analysis on them. Most of the methods are self – explanatory and are listed in Table 7-7:

Table 7-7 Class WSCAHP Method Summary

Method Summary	
private List	**computeTotalWeight**()
public List	**evaluate**() implement the AHP methodology here
private void	**setMyCostThreshold**() specify from the optimal path set
public void	**setMyCostThresholdFactor**(double myCostThresholdFactor)
public void	**setMyCostWeight**(double myCostWeight)
public void	**setMyLUBoundThresholdFactor**(double myLUBoundThresholdFactor)
public void	**setMyReliabilityWeight**(double myReliabilityWeight)
private void	**setMyTimeThreshold**() specify from the optimal path set
public void	**setMyTimeThresholdFactor**(double myTimeThresholdFactor)
public void	**setMyTimeWeight**(double myTimeWeight)

Finally, in order to perform the sensitivity analysis we implement the experiment design methodology. Class **Factor** denotes the experiment factor and holds the information such as factor name, factor levels, etc. Interface **Experiment** defines the general behavior of an experiment. The key method is **doExperiment()** and **doAnalysis()** which are necessary for the subclasses to override and put the specific tasks here.

8 REFERENCES

Environmental advantages of inland barge transportation, 1994. U.S. Department of Transportation, Maritime Administration Public Report.

U.S. inland waterways, 2003. Http://www.mvr.usace.army.mil/navdata/.

Boardman, B., and Malstrom, M. E. 1998. *Intermodal cost analysis software user's manual,* University of Arkansas.

Canada, R. J., Sullivan G. W., and White A. J. 1996. *Capital investment analysis for engineering and management.*

Clemen, T. R., and Reilly, T. 2001. *Making hard decisions with decision tools*. Wadsworth Publishing, Belmont, California.

D'Este, G. 1992a. Frameworks for understanding the behavior of purchasers of general cargo shipping services. *1992 World Conference on Transport Research, Lyons, France.*

D'Este, G. 1992b. Carrier selection in a Ro/Ro ferry trade – Part1. Decision factors and attitudes. *Maritime Policy and Management, 19, 115-126.*

D'Este, G. 1992c. Carrier selection in a Ro/Ro ferry trade - Part2. Conceptual framework for the decision process. *Maritime Policy and Management, 19, 127-138.*

Erickson, C., Grenzeback, L., and Schrieber, J. 1999. *Challenges and opportunities for an ITS/intermodal freight program,* U.S. Department of Transportation, Federal Highway Administration.

Hall, P. K., and Wagner, W. B. 1996. Tank Truck Carrier Selection by Bulk Chemical Shippers: An Empirical Study. *Logistics and Transportation Review, 32(2), 231.*

Harper, D. V., and Evers, P. T. 1993. Competitive issues in intermodal railroad - truck service. *Transportation Journal, 31-45.*

Harps, L. H. 1995. Industry at a crossroads. *Inbound Logistics, 15(15).*

Jennings, B., and Holocomb, M. C. 1996. Beyond containerization: the broader concept of intermodalism. *Transportation Journal, 5-13.*

Johnston, M. L., and Marshall, S. 1993. Shipper perceptions of intermodal equipment. *Transportation Journal, 33, 21-29.*

LOGIQ, The Decision-Making Process in Intermodal Transportation, Deliverable 1. Fourth Framework Programme on RTD, European Commission-Directiorate General TREN, Brussels, 1999.

Rossetti, M. D., Collins, T. R., Sloan, N., Tee, Y., and Chow, M., Kutanoglu, E. 2000. *TLI-AR00-2, Analysis of intermodal choice combinations and pre-positioning strategies for military supplies and materiel,* Defense Logistics Agency.

Mahoney, J. H. 1985. Intermodal freight transportation. *1985 ENO Foundation for Transportation, Westport, Connecticut.*

Mangan, J., Lalwani, C., and Gardner, B. 2001. Identifying relevant variables and modeling the choice process in freight transportation. *International Journal of Maritime Economics, 3(3), 278-297.*

Mentzer, J.T. and Kahn, K.B. 1995. A framework of logistics research. *Journal of Business Logistics, 16(1), 231-50.*

Mickle, G. D., and Burns, K. J. 1978. *Impacts of a waterways user charge on the economy of Tennessee.* Memphis State University

Nachtmann, H. 2002. *Economic evaluation of the impact of waterways on state of Arkansas,* Mack Blackwell Transportation Center.

Rossetti, D. M., & Nachtmann, H. 2003. *MBTC 2024, WebShipCost - intermodal transportation linkage cost assessment via the WWW,* Mack Blackwell Transportation Center.

Saaty, L. T. 1980. *The Analytical Hierarchy Process*. New York: McGraw-Hill.

Shier, D. R. 1974. Computational experience with an algorithm for finding k shortest path in a network. *Journal of the Research of the NBS, 78, 139-164.*

Stank, T. P., and Roath, A. S. 1998. Some propositions on intermodal transportation and logistics facility development: shippers' perspective. *Transportation Journal, 13-23.*

Tsamboulas, Dimitrios, & Kapros, Seraphim, 2002. Decision-Making Process in Intermodal Transportation. *Transportation Research Record*, 1707, 86-93.

Trusty, K., & Malstrom, M. E. 1998. *MBTC-FR-1079, A feasibility assessment of truck-barge intermodal freight transportation,* Mack Blackwell Transportation Center.

U.S. Department of Transportation, Federal Highway Administration Online Public Data. (2002). *Freight analysis framework.* Http://www.ops.fhwa.dot.gov/freight/publications/faf.html.

Wilson, A. R. 2000. Average freight ton-mile transportation price by mode. *Transportation in American*.

Wood, Donald, & Johnson, James, 1995. *Contemporary Transportation*, 5th edition, Prentice Hall.