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Development of a GIS-based routing model

Xinnong Yang

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DEVELOPMENT OF A GIS-BASED ROUTING MODEL

by

Xinnong Yang

A thesis submitted in partial fulfillment of the requirements for the degree of

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in

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Department of Civil and Environmental Engineering
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DEVELOPMENT OF A GIS-BASED
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Department of Civil and Environmental Engineering

ABSTRACT

In recent years, there has been increasing concern related to the safety of hazardous materials transportation. One major aspect of safety relates to routing. Route optimization models deal with multi-criteria or multi-objective optimization problems. The basic objectives of routing problems include transport cost and risk affects. These lead to several related sub-objectives such as optimization of travel time, distance, population exposures or other measures of "risk". An improved model presented in this thesis addresses a new optimization model, "Range Optimization Model". Although the core of the route optimization tools adopted is still the conventional "Shortest Path Algorithm", the definition of route optimization functions and the means to employ "Shortest Path Algorithm" are different from conventional procedures.
Geographic Information Systems (GIS), have been widely used as a spatial database management system and a geographical analysis tool in a variety of fields related to study of environment, transportation engineering, planning and geographical analysis. This thesis develops a prototype GIS-based routing system which includes static routing functions, dynamic routing functions, and emergency response analysis functions. The system implements the route optimization function based on Network Analysis tools and Dynamic Segmentation capabilities of ARC/INFO. By employing multiple input-source menu systems, user-friendly interfaces are designed for users to easily define problems, select the features, perform route selections, edit routes, and query route information in both graphic form and tabular form. A case study using a simplified coverage of the highway network (with hypothetical attributes) in Nevada is used to demonstrate applications of the system.
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1. INTRODUCTION

Each year, there are about 1.5 billion tons of hazardous materials shipped on the transportation network (U.S. DOT, 1990). Hazardous materials, as defined by the Department of Transportation, include explosive materials, flammable materials, poisonous and infectious substances and radioactive materials. The transportation of hazardous materials is an issue of concern because of the risks, real and perceived, that the transport of these materials can pose to public safety and health, as well as the environment. Highly publicized transportation incidents involving explosions and injury or loss of life have heightened the public awareness of the potential dangers in hazardous materials transportation. Consequently, the public tends to view the transport of hazardous materials in terms of worst case scenarios. According to the statistical data from U.S. DOT's Hazardous Materials Information System, highway incidents of hazardous materials transportation over past eight years had amounted to 41,781 and accounted for about 80% of such accidents on all modes. Four fatalities and 287 injuries were reported in 7,163 incidents in the transport of hazardous material on highway in 1990 (U.S. DOT, 1990). Therefore, there is a significantly interest in improving safety of hazardous material transportation.
1.1 Scope of Thesis

One of the major issues of hazardous material transportation is to determine safe and efficient shipping routes for hazardous materials. The primary factors affecting decisions on route selection can be divided into two broad categories: economic and safety considerations. Economic considerations include shipping or transportation costs. Safety factors involve the likelihood of an accident or incident that causes materials release, and potential consequences or direct effects on the population, the property and the environment. Various approaches have been applied to incorporate such criteria in transportation routing models.

According to the activities related to transportation of hazardous materials, problems can be divided into pre-event actions and post-event actions. Pre-event actions are designed to reduce the risks prior to shipment, whereas post-event actions concern emergency response and recovery in case of accidents or incidents. Correspondingly, routing problems can be divided into categories of static routing and dynamic routing. Static routing refers to route selection and shipment schedules when both destination and transportation network conditions are known prior to shipment and are assumed to remain fixed over time. However, dynamic routing takes real-time or nearly real-time information related to transportation operations into account during the process of route selection.

Many factors need to be included when selecting shipment routes. Factors such as travel time, travel distance and population exposure are examples of key variables. Therefore, a multi-objective model would be an appropriate tool for this
purpose. Depending on the availability of traffic data, traffic or network characteristics may be incorporated as constraints. This will help in route selection. The use of Geographic Information System's (GIS) spatial data management and spatial searching function, as well as network features would facilitate the incorporation of such optimization models for route selection. Network analysis functions are used as programming and analysis tools. GIS network functions allow users to operate the system and view the real-time results through both graphical and numerical formats.

In this thesis, a prototype routing analysis system with menu-driven interface using ARC/INFO and Fortran programs is developed to provide a user-friendly analysis and operating environment. Its application is demonstrated using a simplified highway network of Nevada for case study. A generic test database and graphic coverage based on the network are also created for the purpose of experimental study. In review of previous routing modelling techniques, an improved route optimization model is addressed to correct the misunderstanding of the concept of "optimal" route and clarify the interpretation of the results of two objectives: transportation cost and risk. A decision-aid algorithm supported by GIS techniques is approached to seek an optimal route or a satisfactory route. The system includes both static and dynamic routing features. Users can either use preset data or interactively input data for route selection, and may choose scenarios or criteria to define desired objective functions. Graphic display options are available for users to deal with spatial data and review output results graphically.
1.2 Background and Literature Review

A typical model used for routing analysis is the HIGHWAY model developed at the Oak Ridge National Laboratory (Joy, 1991). Based on a highway data base and commercial routing model, the computerized transportation routing model, HIGHWAY, serves as a tool for determining highway routes for transporting hazardous materials. This static routing model uses a "Shortest Path Algorithm" to choose an optimum path by minimizing the total impedance between an origin and a destination. Link impedance in this case is the weighted sum of distance and driving time along a link. Route optimization can also include several constraints, such as bypassing a specific city or a highway intersection.

Efforts have also been made to use multi-objective optimization techniques for routing models. Typical approaches include those by Smith (1989), List (1991 a, b), Abkowitz (1988, 1991), Klein (1991) and Zografos (1989), which allow consideration of multiple objectives such as travel time, distance, population exposures and some other network features such as accidents and shipment security data. The relative importance of the objectives are typically determined by variable weighting factors. The conventional Shortest Path Algorithm is still a primary practical method for solving optimization problems, especially for large transportation networks. Zografos (1989) adopted a goal programming technique to solve a routing model for an experimental network. Some approaches incorporate scheduling into routing problems and add time-of-day-dependent links by using restrictions. Smith developed a hierarchical shortest path algorithm to find an optimum path avoiding rush periods.
of a day. McCord addresses an issue whether technical abilities are sufficient to identify such an optimal route in his recent paper. Klein (1991) applied the concept of fuzzy sets to the problem of transportation of hazardous waste and illustrated how it could lead to better decision-making tools.

The basic variations or factors considered in routing models for hazardous material transportation include:

a) transportation cost which includes travel time and distance,

b) probability of accidents,

c) population exposure,

d) "risk" which is a comprehensive index used as a quantified estimate for the effects caused by undesirable events.

Numerous risk estimate models have appeared in recent years. Typical ones among them are those presented by Saccomano (1993), Abkowitz (1988), Jenssen (1984), Klein (1991) and Theodore (1991). Abkowitz, 1988, presented a risk formula incorporating human health factors and property damage factors. Klein approached a fuzzy model for the transportation of hazardous materials. Jenssen discusses a method developed by Det Norsk Veritas for a rational risk assessment tool and outlines some of the risk analysis techniques. At the same time, inconsistency and uncertainty among these models have greatly increased. As Saccomano states (1993) "despite similarities in the nature of the transport problems, these models have failed to produce agreement on the nature and validity of the reported risk estimate."
Dynamic routing can be defined as finding an optimal path to satisfy multiple objectives and constraints under real-time situations. Dynamic routing problems require special attention for processing real-time inputs and are more critical in time constraints than are static problems. Major objectives for dynamic routing may be scenarios related to time such as travel time, response time, operation time, etc. Other constraints affecting such scenarios include traffic volume, road condition, accident or incident rates. These constraints also need to be taken into consideration. To reduce operation time, user-friendly operating environments and intuitive graphical display become crucial.

The approach using network models and "shortest path algorithm" for route selection requires significant computing resources and data storage capabilities. Geographic Information Systems (GIS) technology provides a powerful tool for analysis, display, evaluation and decision-making in many areas. The application of GIS has enabled significant advances in the storage, retrieval, processing and presentation of vast amounts of geographically referenced data. Some related references include the work of Lee (1991), Johnson (1992), and Mark Abkowitz (1988, 1990, 1992). Abkowitz presented a risk management, routing, and emergency planning software tool (HazTrans) with two components: a mapping system or GIS system and an analysis methodology. Lee discussed differences between static routing and dynamic routing, and approached the potential and feasibility for using GIS to implement computerized routing system.
2. ROUTING ANALYSIS METHODS

Route optimization model is the core of routing systems. The selection and design of the route model greatly affects the implementation of a routing system. Multi-objective optimization techniques have proved to be an effective and useful tool in constructing a route optimization model. An improved route optimization model is addressed in this chapter to overcome the imbalanced risk distribution on a route, which is ignored in most of the previous approaches. A decision-aid algorithm is developed to help find the optimal solutions or quasi-optimal solutions.

2.1 Objectives of Routing Analysis

The most common objective of a routing problem for hazardous material transportation is to find a path which will be used for shipping hazardous materials efficiently and safely. Furthermore, efficiency and safety can be divided into several sub-objectives. Efficiency can be interpreted as minimizing transportation cost or travel time. However, optimizing safety could be an ambiguous criterion. Appropriate measures include minimizing accident rates on the selected route, minimizing population impacts or potential property damage cost along the route, or simply minimizing risks. Selection of criteria or sub-objectives for route selection and
formation of optimization problems is a key issue in hazardous materials routing. There are no models that can incorporate all criteria or factors exhaustively. Therefore selective decisions must be made in choosing the major scenarios for problem-solving.

Data availability is another issue integral to building a routing system. The development of a physical model based on theoretical models depend mostly on the availability of data. Basic data for a typical routing system include highway characteristics, population data and accident data.

The routing problem for hazardous material transportation includes two principal aspects: route optimization models or algorithms and risk assessment functions or utility functions. Route optimization models place emphasis on selecting optimal routes based on some criteria, while risk assessment stresses the quantitative estimation of risk for the transport of hazardous materials. Risk assessment functions or utility functions could serve as effective input to route optimization models or algorithms.

2.2 A Multi-objective Route Optimization Model

The criteria used in route selection influences the form of the objective function. In turn, the objective function could significantly affect the results. Therefore, differently constituted objective functions could lead to significantly different results. There are two kinds of approaches used to incorporate key factors in the objective function. The first is to quantify the total impact based on travel
time, distance, total population risk, traffic accident history, and other such factors into one measure. The measure is then used as the criterion variable in an optimization model to obtain an optimum path. The second approach is to explicitly incorporate all factors being considered into an optimization model and to construct a multi-objective function routine. Often the factors are normalized. The former approach needs more sophisticated statistical techniques and assumptions, whereas the latter requires greater effort in setting up an appropriate optimization model.

The customary shortest path problem is to find a path of minimum length from an origin to a destination when the length of each link in the network is known. The goal of shortest path algorithms is to secure a path with the smallest accumulated impedance. The flow on each node should be conservative, i.e. the inflow should be equal to outflow except at the source and terminal node. This principle can be extended to multi-objective routing models as well.

2.2.1 Multi-objective Optimization Problem

A number of approaches have been proposed for multi-objective linear models for transportation route analysis (James 1982, List 1991, Smith 1989, Zografos 1989). There are three primary approaches or philosophies that form the basis for nearly all the candidate multiple objectives techniques that have been proposed. The three approaches or philosophies can be summarized as:

1. Weighting or utility methods
2. Ranking or prioritizing methods
3. Efficient solution methods

A multi-objective optimization problem or a multi-objective mathematical program is a problem which aims to find a vector \( x \) satisfying constraints of the type

\[ h_i(x) \leq 0, \quad i = 1, 2, \ldots, m, \]

obeying eventual integrality conditions and maximizing or minimizing functions

\[ g_j(x), \quad j = 1, 2, \ldots, n, \]

Generally, if both constraints and objective functions are linear, the problem becomes linear multi-objective programming problem:

\[
\begin{align*}
\text{max } & \mathbf{C}x, \\
\text{subject to } & \mathbf{D}x \leq \mathbf{b}, \\
& x \geq 0,
\end{align*}
\]

where \( \mathbf{C}, \mathbf{x}, \mathbf{D} \) and \( \mathbf{b} \) are matrices of respective dimensions \( \times p, p \times 1, m \times p \) and \( m \times 1 \).

One of three techniques stated above can be adopted to solve this multi-objective problem. The simplest approach is the weighting method which refers to those approaches that attempt to express all the objectives in terms of a single measure. The basic thrust of all such methods is to transform a multiple-objective model into a single-objective function.

The ranking or prioritizing methods try to circumvent the heady problems in developing truly credible weights. Rather than attempting to find a numerical weight for each objective, objectives are simply ranked according to their perceived importance. The problem with the ranking approach is how to associate the results of a given solution to the satisfaction of the ranking.
The efficient solution method tries to "avoid" both the problems of finding weights and that of satisfying the ranking by generating the total set of all the efficient solutions (or nondominated solutions, or Pareto optimal solutions). From these solutions, the decision maker selects the one believed to be most attractive.

The main difficulty in using such multi-objective problems for hazardous materials transportation analysis is the fact that it is an ill-defined mathematical problem. There is usually no absolute optimal solution acceptable to every one. Therefore, the formulation or definition of the objective function greatly depends on perception or expected preferences. The key variables, the weights assigned to these variables and the constraints formulated are all greatly influenced by such preferences.

2.2.2 Risk Analysis

A major risk of transporting hazardous materials arises from the potential consequences of releases that might occur either along route segments, or at loading and unloading facilities. There are two possible scenarios in evaluating the impacts of hazardous material transportation. The first consider the consequences of releases caused by accidents during shipment. The other consider the consequences of routine shipment under accident-free and incident-free condition. Such consequences include radiation doses and risks to the public living near or travelling on public highways, and occupational exposure. Risk estimation considers probabilities related to several factors:
1. Accident probability

2. Conditional probability of containment release given an accident

3. Volume and rate of material released

4. Consequences of population impacted and property damage

The selection of factors is a function of the type of hazardous materials. Each component of risk requires specifications of separate sub-models with a unique set of inputs/outputs.

Various accident probability estimates have appeared in the literature. One method is direct reference to accident data. Another is the output of statistical models developed for any mix of mitigating factors. Release probability generally requires the occurrence of an accident involving hazardous materials. Estimates of accident-induced release probabilities are obtained in two ways: direct reference to the accident spill data or as a product of a fault tree analysis of containment system failure in an accident situation. Estimates of consequences depend on the nature of the hazardous material involved, dispersion of the materials, containment of the area, emergency response, and basic assumptions used by various sources.

Saccomanno (1993) summarized several risk analysis models developed in North America and Europe for the transport of dangerous goods. Saccomanno concludes that the application of these models to a common transport problems explains much of the variability in risk caused by assumptions and differences in data. Significant variations and contradictory conclusions result from three basic sources:

1. Underlying assumptions governing the estimates.
2. Jurisdictional differences concerning the validation and application of the models.

3. Structural differences in the models themselves.

Some of this variability in the estimates remains unexplained. Detailed discussions of methodologies and modeling of risk estimate are not addressed in this thesis. In this prototype routing system, a simplified risk estimate model is applied for major factors including accident probability and population exposure. Risk is represented as a product of release-causing accident likelihood and exposed population. The risk value on link "i" is given as:

$$Risk \quad R_{i} = ACCIDRATE_{i} \times POP_{i}$$

Where

- $R_{i}$ - Risk value
- $ACCIDRATE_{i}$ - Accident rate on link $i$
- $POP_{i}$ - Population density buffering on link $i$

### 2.2.3 Proposed Routing Model

Early approaches to routing of hazardous material transportation focused on developing techniques for formation of the problem and quantifying variables. However greater emphasis has been placed on techniques to incorporate more scenarios in the model. These range from simple models which consider time and distance (Joy et al, 1991 and Peterson, 1991) to more complicated models with accident rate likelihood, population exposure, property damage and risk assessment
(Abkowitz 1988, Zografos 1990, List 1991). The techniques used in these cases are the shortest path algorithm for network optimization and the weighting or utility method for multi-objective optimization. Although more sophisticated models such as goal programming and fuzzy programming have been developed to improve the optimal results, the optimization model of the routing problem can be essentially formulated as follows:

\[
\text{Minimize} \sum F(x_i)
\]

subject to

\[
G(x_i) \leq c_i \quad i = 1, 2, \ldots, n,
\]

where

\[
F'(x_j) = [f_1(x_j), f_2(x_j), \ldots, \ldots,]
\]

which is a goal vector with each subgoal \(f_i(x_j)\)

and

\[
G(x_i) \quad \text{is a constraint vector},
\]

and

\[
x_i = 1 \quad \text{when the } i\text{th link is picked as a part of the path}
\]

\[
x_i = 0 \quad \text{otherwise}
\]

A typical multi-objective linear programming model proposed for incorporating transportation cost and risk as two major objectives is given as
Minimize \( \sum_{i=1}^{k} D_i x_i (w_1 N_1 C_i + w_2 N_2 R_i) \)

where

\( D_i \) — effective value of network infrastructure or other characteristics for link \( i \)

\( w_1, w_2 \) — weighting coefficient

\( N_1, N_2 \) — Normalizing multiplier

\( C_i \) — Transportation cost for link \( i \)

\( R_i \) — Risk value for link \( i \)

The basic constraints for network flows are

\[
\sum_{i \in \mathcal{N}_o} x_i - \sum_{i \in \mathcal{N}_t} x_i = b_k
\]

where

\( k = 1, 2, 3, \ldots, n \)

\( b_s = +1, b_t = -1 \)

\( b_i = 0 \) for \( k \) not equal \( s, t \)

\( s = \) source node

\( t = \) terminal node

\( \mathcal{N}_o = \{k | o_i = k\} \) - the general list of arcs with origin node \( k \)

\( \mathcal{N}_t = \{k | T_i = k\} \) - the general list of arcs with ending node \( k \)

flow constraint:

\( x_i = 1 \) if the link \( k \) is selected

\( x_i = 0 \) otherwise
Depending on the data available, several alternative constraints can be chosen from:

. Capacity flow constraints
. Population density limits
. Highway network characteristics constraints
. Other factors imposed on the problem when specific safety concerns are present

Capacity flow constraints provide users an option to avoid traffic congestion in selecting route. Population density is a primary concern in shipping hazardous materials. Usually a route for hazardous material transportation should consider a detour around areas with high population density. Highway network characteristics, such as median type, pavement type, functional classifications, etc., will also significantly affect the results of route selection.

2.3 Problems and Drawback of Conventional Routing Models

As pointed out in the literature (McCord 1993, Saccomanno 1993), the models used for the routing problem of hazardous materials transportation have some potential problems. One of the major problems is how to balance competing objectives. Decisions should be made by users to distribute the weighting values or utility coefficients. There are few rules available to help assign these weights other than preference. Another problem is the difficulty in interpreting the results. As stated earlier, the goal of the problem is to find an efficient and safe path for shipping hazardous materials. Is the result obtained really efficient, or safe, or both
efficient and safe? Because of the conflict between efficiency and safety, what kind of compromise between them is required? What degree of safety is gained from the result? How can the results help decision makers to make a decision? Practically, an optimal solution may not be found to answer all the above-mentioned questions and satisfactory answers may not be achieved.

Another problem is uncertainty arising from the route optimization and risk assessment procedure. In other words, different optimal functions, different ways to balance the objectives and different weighting distributions may result in different solutions. These uncertainties stem from various sources such as different assumptions, different data sources, and different models. Even for the same model, they may yield different results based on some of these factors. One reason is that too many factors affect the determination of an optimal path. Current technologies only allow one to consider a few scenarios and constraints in determining an optimal path. There are two major obstructions limiting the number of factors to be incorporated in the function. The first is the difficulty of balancing many objectives and obtaining optimal solution for a large scale problem. The second is the building and manipulation of an efficient network database for storing all spatial and tabular data for routing optimization.

More serious problems lie in the assumption of safety which is implied in the routing model, i.e., the less the total risk value a path has, the safer it is. However, it may not be true. A path with minimum total risk values could contain some segments with high risk values. The reason why these high risk segments are chosen
as optimal paths is because the other segments have risk values so low that the sum of total risk values for all the segments aggregated become minimum. Obviously, a path with one or more high risk segments may not be a safe route no matter how low the total risk value is.

Examples with such a problem are shown in following figure 2.1. A route (1 - 2 - 5 - 4 - 6) with overall minimum risk value is shown in double line. Although the risk value of segment 4-5 is 10, the overall risk values is still minimum (total risk = 20.0, the largest link value = 10.0) when compared with the route 1 - 2 - 3 - 4 - 6 (total risk = 21.0, the largest link value = 6.0). This is because the risk value of segment 2-5 is so low (1.0). Actually, a route with a largest link value of 6.0 may be preferred to a route with a largest link value 10.0, regardless of the overall risk value.

![Figure 2.1 Example of an "optimal" route with imbalanced risk values](image-url)
Basic problems existing in assumptions and definition of objectives cause unacceptable "optimal" results. A safe route may be defined as one for which risk values for all segments are within a certain range. This range should represent the tolerable or acceptable level of risks.

Currently used optimization path finding algorithms approach overall optimization and neglect the effects on the segmentation of the path. For example, the shortest path algorithm seeks a shortest path from origin to destination. It does not consider the impedance value on each link. If the objective is time or distance, the overall minimum objective represents optimal solutions. But if the objectives are risks or accident rate, the overall optimal result can not guarantee the lowest risk value on each segment. Actually, this kind of imbalanced path with some high risk segments may not be preferred when hazardous materials are shipped, even though the total risk value is the lowest.

2.4 A Modified Route Optimization Model

The routing problem of hazardous material transportation is in fact a network optimization problem with multi-objectives or multi-criteria. It is neither only a multi-objectives optimization problem, nor only a network optimization problem. It is a complex optimization problem with both characteristics.

Given a network with a group of links and nodes, network optimization techniques (NOT) try to find one or more paths with minimum cost or time, or with maximum flow, or with maximum flow and minimum cost. One point worthy to be
noted is that NOT deals with a group of arcs and nodes. Each has its own attributes (time, cost and flow). Although the result or solution is total or overall optimal, it is not necessarily locally optimal.

A new definition of a safe route needs to be made to solve the problem stated above. Two other assumptions are necessary. First, a route will be made up of one or more segments called arcs. If there is only one arc on the route, the total risk value is equal to the segment risk value. Secondly, the risk value actually is a random variable so we should assume that risk values on each arc are independent. This ensures that segment risk values can be evaluated individually. Therefore, a safe route can be interpreted as one in which risk values of all individual segments are within a desirable range. According to the understanding and interpretation of a safe route, a safe route should only contain arcs (segments) with small variances. In other words, if only risk factors are considered, an optimal path should include a group of arcs with risk values falling into a least risk range (Note: this refers to a least risk range rather than the lowest total risk value on a route). Intuitively, a simple way to implement this is to add risk constraints to the previously defined optimization model:

\[
\text{Minimize}\sum (w_1 N_1 C_i x_i + w_2 N_2 R_i x_i)
\]

subject to

\[
LR = < R_i <= UR
\]

where \( LR \) and \( UR \) are acceptable lower-limit and upper-limit of risk values. A simple example of risk value limits may be accident rate per million vehicle miles of travel in which case the lower and upper limit may be \( LR = 0, UR = 2.5 \times 10^4 \).
However, the questions regarding this model will soon rise. How do we decide the UR and LR to ensure safety? There is no absolute standard to measure risk value. Therefore, no feasible way exists to determine upper-limit risk values or lower-limit risk values prior to solving the problem. Further, are the "optimum" solutions from the above model really superior to other solutions? Maybe a route exists with less cost and smaller risk variances although the sums of the total costs and total risk values are bigger than the "optimum solution". If the total risk value is no longer a good criterion, the risk value as an objective in objective functions is meaningless. Why keep it in an objective function? On the other hand, a mixed solution which combines cost and risk value creates more difficulties to understand and interpret.

A reasonable model would be:

\[
\text{Minimize } F = \left( \sum D_i N_j C_i x_j \right), \quad RR = (UR-LR)
\]

The following constraints ensure a route from source node "s" to terminal node "t"

\[
\sum_{i \in M_s} x_i - \sum_{i \in M_t} x_i = b_k
\]

where

- \( D_i \) -- effect value of network infrastructure or other characteristics for link \( i \)
- \( N1 \) -- Normalizing multiplier
- \( C_i \) -- Transportation cost for link \( i \)
- \( k = 1, 2, 3, \ldots, n \)
\[ b_s = +1, \ b_t = -1 \]
\[ b_i = 0 \text{ for } k \neq s, t \]
\[ s = \text{source node} \]
\[ t = \text{terminal node} \]

\[ M_{sk} = \{ k | o_i = k \} - \text{the general list of arcs with origin node } k \]
\[ M_{Tk} = \{ k | T_i = k \} - \text{the general list of arcs with ending node } k \]

Flow constraint:
\[ x_i = 1 \quad \text{if the link } k \text{ is selected} \]
\[ x_i = 0 \quad \text{otherwise} \]

Risk constraint:
\[ LR < R_i < UR \]

Instead of risk value, the new model includes the difference between lower risk limit and higher risk limit into the objective function. The new model is formulated to seek a route with minimum cost "C" and least risk variance "RR". In most cases, lower limit LR is equal to zero, so RR = UR. Then the objective is to minimize the upper risk limit. This routing optimization problem has two objectives. This problem differs from conventional optimization problems which include only variables in the objective function, in that constraints are included in the objective function.

At first glance, the model seems complicated and difficult to solve, careful study shows that the value RR not only constrains risk values but also shrinks the feasible solution set. The lower the RR value is, the smaller the feasible solution set becomes. Theoretically, as RR reduces, the feasible solution set of the problem
shrinks until the last solution set -- the optimal solution set. Even if the optimal solution can be found, it may not necessarily be practically feasible. If the cost objective compromises with the risk objective, UR value does not need to be reduced to a critical point which is not practically effective. Therefore a reasonable RR value could be found based on available information or expert opinion. The new model not only provides a reference for risk limits, and helps decision maker determine risk constraints, but also clarifies the interpretation and understanding of the solutions of two objectives.

By employing statistical characteristics of risk variables, a trial of applying the route optimization problems uses a mean value of risk values on the network. The model is presented as

\[
\begin{align*}
\min F &= \left( \sum_1^k D_i N_i C_j X_j, MR = (UM-\text{LM}) \right) \\
\text{subject to} \quad \text{LM} \leq R_i \leq \text{UM}
\end{align*}
\]

where LM and UM are Lower-Mean and Upper-Mean.

A typical example to assign LM and UM is given as,

\[
LM = 0, \quad UM = \frac{\sum R_i}{k}
\]
k -- number of arcs in previous selected network

This model has the same format as the previous one except the means of risk value are used as lower and upper limits instead of absolute risk value. There also exists the potential of no feasible solution when MR values become small. Further, the determination of a mean value may greatly affect the results and even whether a feasible solution exists.

A more sophisticated model may be tried based on modified deviation of risk value on each link. A basic problem arising in formation of the problem is how to choose a mean value as the centroid of deviation. Depending on different kinds of constraints, we can set a minimum risk value among all links as a mean value if we only want to consider upper-limit risk. We can also use a mean value of risk values of all links in the network as centroid. On the other hand, a value between minimum value and mean value of all links in the network could be adopted as centroid. An optimum model can then be formulated as:

\[
\text{Min } (w_i N_i \sum_{i=1}^{k} C_i X_i , \ UD)
\]

subject to

\[
(R_i - \text{MEAN})^2 \leq UD
\]

where UD is Upper-Deviation of risk values.

This model can be used to find a route with a minimum risk deviation around a centroid or a mean value and minimize the variations among segments along a route. Although the model theoretically can overcome imbalanced risk value
variations on each arc, the solution to the model greatly depends on the choice of a mean value.

2.5 A Decision-aid Algorithm for Solving the Routing Model Using GIS

As discussed in the last section, the solution set will shrink with the reduction of RR value. Theoretically, an optimum solution set can be found by decreasing RR value to an appropriate value. However, finding an optimal solution set can be very demanding. Therefore, an algorithm to find a quasi-optimal solution is suggested and developed.

The difficulty in solving the above objective function lies with finding an appropriate UR or LR value. Usually LR is assigned as zero, but UR value is more flexible. If UR is too high, the solution may include high risk arcs. If it is too low, the route chosen may have greater than desirable transportation cost, or even no feasible solution. Actually UR could be used to balance the weights between risk and transport cost. A least transport cost route without considering risks could be obtained by letting UR be unbounded, i.e.,

\[ UR = \infty \]

Conversely, a route with the lowest UR value is supposed to represent the route with the least risk. However, neither route may be the best choice. So an appropriate choice of UR value might yield a route with a reasonable compromise between transport cost and risk.
Users need to decide the degree of the compromise, an appropriate UR value to implement the route optimization model. But as stated earlier, since a risk value is a non-perceived value, it is extremely difficult to select a suitable value without any help. Therefore a computerized decision-aid system could be used for this purpose.

The purpose of the decision-aid system is to provide users with the range of candidate UR values for a route between an origin and a destination. One of the decision-aid algorithms for determining UR value is illustrated in figure 2.2.

The left path of the diagram illustrates a way to find a maximum risk upper-limit value on a least cost (Cmin) route without any risk constraints, which would limit the upper searching range of UR. That guarantees a least cost route exists with risk values lower than or equal to that value. In other words, nothing is gained by trying risk value higher than that value.

Note that the right path of the diagram establishes a lowest value for risk upper-limit. In other words, no route exists if UR is less than URm.

Search for a least cost route by starting from URm. If no route is found, increase UR value until a route is found. If the cost of the route is equal to Cmin, stop search. The route just found is a optimum solution. Usually, the cost of the route is greater than Cmin. So decisions must be made at this point. Should risk be increased to decrease the cost and how much should risk be increased? If both cost and risk of the route are satisfactory, a satisfied solution is found. Otherwise, the desirable transportation cost may be achieved by increasing the risk constraints.
Define origin and destination

Find a least transport cost Cmin route without considering risks

Find the minimum risk value among all the links connecting to the origin UR1

Find the maximum risk value of a link on the route, URmax

Find the minimum risk value among all the links connected to the destination UR2

Choose a UR value within URm <= UR <= URmax incrementally, starting from URm

URm = max(UR1, UR2)

Searching a least cost C, route with constraint risk <= UR

If C, = Cmin?

If C, < C,?

Increase UR again?

Stop! The optimum solution is found

Replace route i-1 with route i

Satisfied route found

Figure 2.2 Algorithm for Determining UR Value
Sometimes, increasing risk constraints can not guarantee finding a route with less cost. So only a route with less cost than a previous one is kept. Eventually, a feasible solution may be found by choosing UR between URm and UR^*.

But the mathematical solution of the algorithm shown in figure 2.2 involves multiple optimization operations and needs a more complicated implementation method, which is not suggested in this approach. A group of practical decision-aid tools are developed using statistics methods, Geographical Information System techniques to aid decision maker visually and interactively determine UR value. The statistical tools will calculate the maximum, minimum and mean risk values, which may help the user determine the range of UR value. Users can also browse the risk values on all links. Upon assigning a UR value, one may preview the selected results graphically, which could be used for later route selection. There is also a statistical function for a specific route, which is used to determine URmin or to analyze the routing results.

The network analysis tools of GIS and a group of fortran programs are used to implement the optimization functions. Depending on the scenario to be considered in the optimization functions, a data pre-process program retrieves the related data on each link into a temporary data file. Then the program computes the constraint functions for each link and forms a basic optimization model according to parameters defined by users. Finally optimization function values calculated by the program for each link will be stored in an attribute named impedance which has a
feedback to the routing system. A path finding program in GIS is applied to determine an optimum path.
3. NETWORK ANALYSIS AND DATA MODEL

In this chapter, basic network structure and data models for a routing system will be introduced. With the help of Geographic Information System, a network database is designed to store, link and query spatial data and tabular data by their spatial features. A discussion on data structure of the system will help understand how the routing system works.

3.1 Transportation Network and Data Model

A typical transportation network consists of a set of connected links which are used for the movement of people and the transportation and distribution of goods and services. A transportation network can be classified into highway, railway, urban transportation, transit, and local transportation network depending on the type of infrastructure and purpose of the network. The form, capacity and efficiency of these networks have a substantial impact on the standard of transportation and affects our perception of the world around us.

In general, a network is a system of interconnected linear features through which resources are transported or communication is achieved. The network data model is an abstract representation of the components and characteristics of a real-
world network system. The key to producing a successful network model is to understand the relationship between the characteristics of physical network systems and the representation of those characteristics by the elements of the network model.

3.2 Network Data Structure and Data Files

A hierarchical data structure is suggested for the network routing system. To implement this concept, a GIS network data model is adopted. ARC/INFO (ESRI, 1991) software, running on a Unix platform (Sun 690 MP), is used as the GIS program to support this thesis.

The data required by the prototype dynamic routing system can be classified into two broad categories: spatial and tabular data. Spatial data refer to coordinates and their spatial relationships in a transport network. Tabular data refer to two kinds of information. One is the basic or infrastructure data associated with links and nodes in the transport network. The other is environmental data such as population, traffic accident rate, risks, floods etc..

The hierarchical data structure of transportation can be best represented by GIS network data files which break the network data files into:

- Link(AAT) -- The data representing real-world structures such as highways, railways and shipping lanes of transportation.
- Node (NAT) -- The data representing intersections and interchanges of a road network.
Stop (STP) -- The data representing locations or destinations which must be included in the route.

Center (CTR) -- The data representing locations for resource distribution and vehicles dispatching.

Barrier (BAR) -- The data representing nodes prohibited to pass

In addition, the route systems are used to store linear feature data and routing results. These files are associated with a network coverage. For example, if a coverage is named as "NET", then link file is represented by "NET.AAT". So are node files and others. Each data file has a common link identifier, i.e., user-id such as NET-ID which is important for linkages among files. When a network system is operated, data files are automatically linked upon request. Data structures of a network are shown graphically in figure 3.1.

3.2.1 Link Data File

As soon as a network coverage is established, the link data file (AAT) is automatically created in the GIS which includes basic items for representing the link. Spatial data (figure 3.3) include from-node, to-node and link-id. Tabular data (figure 3.2) are not fixed and can be added based on needs of the desired network applications. Data items for the routing system are suggested as follows:

**Infrastructure Data**

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>real world length of the link</td>
</tr>
<tr>
<td>Travel time</td>
<td>normal average travel time</td>
</tr>
<tr>
<td>Pavement types</td>
<td>the types of pavement on the road</td>
</tr>
</tbody>
</table>
Impedance: the cost associated with traversing an entire network link
Street name: real world road name if any
One-way: one-way or two-way highway
No. of lanes: number of lanes on the link
Divided/undivided: divided road or undivided road
Function-class: functional classification

Network Data

- Link File AAT
- Node File NAT
- Barrier File BAR
- Stop File STP
- Center File CTR
- Route System

Figure 3.1 Network Data Structure

Environmental Data

- Risk: perceived risk value
- Population: average population density along the link
- Accident rate: average accident rate along the link
- School: average number of school student on the link
Figure 3.2 Link Tabular Data Structure
3.2.2 Node Data File

Node data file (NAT) mainly records the spatial data related to points such as node number, longitude(or x-coordinate), latitude(or y-coordinate). Additional information or items can be added to each node based on specific needs. The structure of node data structure is shown in figure 3.4.
3.2.3 Stop Data File

The attributes of stops are contained in a user-created INFO file referred to as a stop file. This file defines locations of the stops by referencing the User-ID of the nodes where stops are located, and includes items defining the properties of the stops (figure 3.5). The stop files may be used for stop point where a path will pass.

3.2.4 Center Data File

The attributes of centers are contained in a user-created INFO file called a center file, which is analogous to the stops file in structure as shown in figure 3.6. The centers are used to represent the response centers in allocation function.

3.3 Route System and Dynamic Segmentation

GIS applications in transportation have specific data requirements. Much of the vast quantity of data which transportation agencies routinely collect is recorded using a linear referencing system along a particular route. Linear distances are sometimes referred to as linear measures and related to events such as location of accident or bus stops in terms of "milepoint" location, which is actually one dimensional. But, the arc-node topological GIS produces two-dimensional networks with x and y directions, which means the methods referencing linear feature against two dimensional network are required. There are many applications which use linear objects as their primary geographical reference, e.g. highway pavement characteristics,
Figure 3.5 Stop Data Structure

Stop Data File

- cover-id
- in_order_item
- route_id_item
- impedance_item
- transfer_item

Figure 3.6 The Center Data Structure

Center Data File

- cover-id
- route-id-item
- max-impedance-item
- supply-item
traffic accidents, speed zone, and traffic volume. Such data may be categorized as point, linear and continuous events along a route.

The dynamic segmentation software capability of ARC/INFO (ESRI, 1991, 1992, 993) provides an efficient and powerful tool to store, represent, query and analyze data associated with linear features. Instead of using x, y coordinates, it uses route-measure recording methods, and links databases in a route-measure format to existing linear features. The measuring system is a linear method consisting of a starting value and other values along the route; for example, mileposts along a highway.

![Route Measure System](image)

**Figure 3.7 Route Measure System** (Source: ESRI, 1992)

Dynamic segmentation demonstrates the ability to associate multiple sets of attributes with any segment of a linear feature without changing descriptions of the feature.

The use of a route-system by NETWORK enables the display and analysis of the results obtained from network analysis using the dynamic segmentation features of ARC/INFO. The results of NETWORK analysis such as PATH, TOUR or ALLOCATE are stored in route-system specified by NETCOVER command.
The basic data structure of a route-system includes three data files or tables, i.e. route attribute table, section table, and event table. Figure 3.8 illustrates the relationship and structure of a route-system.

![Figure 3.8 The Structure of Route System Data Model](image)

The route attribute table (RAT) and section table (SEC) are feature attribute tables stored as INFO data files. These are automatically created and maintained by ARC/INFO. A RAT and a SEC together compose a route-system. These are discussed below.

The route attribute table contains items which identify the sections that make up that route. An RAT can consist of many routes making up a particular route-
system. For example, in a bus route system, there are various routes for different bus lines.

An SEC contains several items which define the start and end of the sections. A section represents all or part of an arc. Each section is assigned a "from" and "to" position (f-pos, t-pos) defining its beginning and ending position on the arc. Each section is also assigned a starting and ending value or measure (f-meas, t-meas) based on its position within a route. Sections can have user-defined attributes associated with them. Following table gives an example for section table of bus route system.

<table>
<thead>
<tr>
<th>routlink#</th>
<th>arclink#</th>
<th>f-meas</th>
<th>t-meas</th>
<th>f-pos</th>
<th>t-pos</th>
<th>bus#</th>
<th>bus-id</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>54</td>
<td>40</td>
<td>100</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>54</td>
<td>109</td>
<td>0</td>
<td>100</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>109</td>
<td>151</td>
<td>0</td>
<td>40</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Event databases are composed of a group of tables containing attributes with linear features in terms of the same measures system defined within a route-system. They may be INFO files or external Relational Database Management System (RDBMS) tables. Depending on the type of linear features, event databases can be classified into three kinds of event tables: point, linear and continuous. One of important features of events is that they are independent of ARC/INFO coverages, which allows them to be maintained in an INFO data file or any other supported RDBMS such as INGRES or ORACLE.
4. IMPLEMENTATION OF THE ROUTING SYSTEM USING GIS

This chapter presents the philosophy and techniques adopted in implementing and setting up a GIS route selection system for hazardous materials transportation. The system presented in this chapter (figure 4.1) is developed for a generic approach.

Figure 4.1 Overview of the System Design
of routing analysis for hazardous material transportation by using GIS as a core analysis tool incorporated with other programming tools like Fortran, C language.

4.1 System Design

The routing system includes three major subsystems (figure 4.1). Static routing subsystem provides users options for assigning basic impedance, road characteristics and risk constraint values to perform route selection. Dynamic routing subsystem performs real-time route update and selection based on real-time information, it also allow users to set barriers, stops to alter the route for specific purposes. Emergency subsystem can be used to allocate responder centers and response ranges, also to find a quickest response routes to incident location. An overview of the system architecture is presented in figure 4.2.

A Nevada highway network is used as a case study for developing the coverage (map) to be input to GIS environment. A spatial hierarchical database associated with the coverage is also created. So, the system is basically composed of a group of analytical tools and models, and a network coverage with a spatial database, and user-friendly menu interfaces.

4.2 Static Routing Model

Static routings refer to the route selection procedures when the locations and routing information are all known prior to operation. The development and implementation of a static routing model are discussed in this section.
4.2.1 Static Model and Components

The basic components of a static routing model are travel distance, travel time, network characteristics and risk effects. Depending on the application requirements, the user can choose some of the components to constitute the objective function. For example it could include travel time, distance and risk. Generally, if $N_d$ and $N_k$ are normalizing multipliers, $D_i$ distance on link i, $T_i$ travel time on link i, "s" source
node, "t" terminal node, $M_{oi}$ and $M_{ti}$ are the general list of arcs with origin node $i$ and ending node $i$ respectively, the optimization model can be given as:

1) $\text{Min}: \sum_{k=1}^{m} [\alpha_1 h_{k1} f_k + \alpha_2 h_{k2} f_k]$

2) $\text{Min}(U \cap R \leq UR)$

subject to:

First level constraints described by

$$\sum_{k \in M_{oi}} f_k - \sum_{k \in M_{ti}} f_k = b_i$$

and second level constraints incorporating consideration such as

- One-way or Two-way
- Number of lane constraints
- Divided/undivided facilities
- Pavement type
- Functional classification

where

$$h_{k1} = N_d D_k$$

$$h_{k2} = N_t T_k$$

$$\alpha_1 + \alpha_2 = 1$$

and

$$R_i \quad \text{-- Risk value on link i}$$

$$N_d, N_t \quad \text{-- Normalizing Multipliers}$$

$$D_i \quad \text{-- Distance on link i}$$
$T_i$ -- Travel time on link $i$

$i = 1, 2, 3, ..., n$

$b_s = +1$, $b_t = -1$

$b_i = 0$ for $i$ not equal $s, t$

$s = \text{source node}$

$t = \text{terminal node}$

$h_k = \text{impedance of link } k$

$M_{oi} = \{k|o_k = i\} -- \text{the general list of arcs with origin node } i$

$M_{ti} = \{k|T_k = i\} -- \text{the general list of arcs with ending node } i$

flow constraint:

$$f_k = 1 \quad \text{if the link } k \text{ is selected}$$

$$f_k = 0 \quad \text{otherwise}$$

The model includes two basic objectives and associated constraints. As discussed in Chapter 2, the first objective function minimizes cost of a route; the second objective function tries to find a minimum upper risk limit to bound all risk values on the route. The first level constraints ensure the existence of a route. The second constraints are to account for desired roadway characteristics. The third constraint is introduced for risk value restriction. All these required variable values can be obtained from database associated with the coverage. For the risk assessment, population impact and accident rate are included in the estimation model. The risk estimation model depends primarily on related data available and reasonable assumptions. Detailed discussions on risk assessment is beyond the scope of this
thesis. The implementation of static routing models by using ARC/INFO routing models is discussed next.

4.2.2 Implementation using ARC/INFO

To implement the static route optimization model, ARC/INFO is used to help develop the routing system. First, a new item, impedance, is added to the coverage data file to accommodate the time and distance objectives, which is defined as

\[ \text{imp} = \alpha_1 \text{Time} + \alpha_2 \text{Distance}, \quad \alpha_1 + \alpha_2 = 1 \]

Basically, one can adjust \( \alpha_1 \) from 0 to 1 to assign the relative weights for travel time and distance.

The constraints of road characteristics are implemented by using "reselect" function to select the desired road features. The system can display the roads with different features such as functional classifications, pavement types, median type and number of lanes in different colors on the screen. The button and input type menu are designed to facilitate easy road feature selection. This menu system can not only be used for route selection, but may also be applied in display and analysis of road pavement types, functional classifications and other road feature analyses.

A group of decision-aid tools may be used to help users to determine the upper bound of the risk value. An AML program is developed to combine statistical functions, spatial operation commands in ARCPLOT, and menu commands to implement the statistics, browsing, and preview functions.
The pathfinding option will display the network area one selects for performing a route selection based on road characteristics and risk factors. Users are asked to input the departure point and destination point interactively by using the mouse. The system will execute Pathfinding commands automatically, and the optimal route will be graphically displayed on the screen. The route selection results are automatically saved to the specified route system.

4.3 Dynamic Routing Model

Most dynamic vehicle algorithms are developed for vehicle allocation rather than for vehicle routing purposes. In its simplest forms, a dynamic vehicle routing system usually adopts static routing algorithms and runs them again every time a real-time input is received.

4.3.1 Definitions and Methods of Dynamic Routing

Dynamic routing can be defined as the route selection to satisfy multiple demands for services that evolve in a real-time fashion. There are many differences between static and dynamic vehicle routing problems. In a dynamic situation, the time dimension usually is essential and the routing problems may be more flexible. Future information may be imprecise or unknown prior to routing or the execution of routes. Therefore, an efficient information update mechanism is essential. In addition to the time constraints, resequencing and re-assignment decisions may be warranted because of real-time inputs. Usually, fast computational speed and fast on-
line access to the system and to the database are necessary to support near-real time analysis.

A static routing system has the luxury having deterministic inputs in advance. Solution speed is less critical; however, in a dynamic setting, the routing system is subject to imprecise or unknown inputs as well as greater time constraints. In many situations, a dynamic routing system would be forced to adapt heuristic procedures (mostly local re-routings) to accommodate real-time inputs for quicker solutions which may not always be optimal.

Based on the above philosophy, there are two kinds of routing executions designed in the system. One is the re-routing execution based on a previously known or selected route. This provides an initial solution to the routing problem. So the system will keep all the criteria used for the static route such as basic impedances and road characteristics, and select the optimum route on real-time settings assigned interactively by an operator. The real-time settings include setting barriers, blocking street, and reassigning stops. These functions allow people to block some streets, prevent the vehicles from passing through dangerous areas and force the vehicles to take a detours in case of incidents or unpredictable events. New route selection processes will select a route for detouring the barriers and blocked streets, passing assigned stops.

Another kind of routing execution is the quick routing or direct routing without considering any constraints. Users can optionally set barriers or block streets, and assign stops, and immediately execute the pathfinding. This function may be
used for temporary route selection or local route alternatives to account for real-time events.

4.3.2 GIS Implementation

The major tools used for implementing dynamic routing are File Input/output functions and network analysis tools. All parameters applied in the previous route selection must be saved in specific files. When the route name and route number are entered, the parameters for previous routing will be retrieved for current routing.

Due to the limitation of the GIS software, specific tools for assigning barriers and stops and creating data files were not readily available. Therefore, a group of macro (AML) programs combining basic Arcplot functions were developed to implement point selection and store the results in Info data files.

To perform the pathfinding function, the program will find an optimum path from starting point via the stops assigned and avoiding the barriers to the destination based on previous selection criteria.

4.4 Emergency Response

The core of an emergency response routing algorithm is the quickest path algorithm. An important characteristic of an emergency response problem is that the time objective carries overwhelming weights compared other objectives. The emergency response problem must also account for different constraints.
There are two basic functions in the emergency response model: allocation and emergency routing (figure 4.3). Before the operation of the route selection module, all the response centers should be located on the network. Then, the network is divided into several areas or zones according to the response time for each response center. This is done by using Allocate module of ARC/INFO. Allocation results are saved into center files grouping as different routing systems. Before executing the Allocate function, a center file must be created. This can be done by using Info commands outside the menu system, or one may choose the option provided by the system to interactively select the centers by using a mouse, and input maximum time.

![Diagram](image)

**Figure 4.3 Procedure for Emergency Response Analysis**
The system will then automatically create the center file and save it by the name designated by users. The Allocation function is executed based on the center file and time impedance assigned. Therefore, it is important to be certain about the right center file name and the maximum impedance data.

The second function in the emergency response module is emergency response routing. After having finished the interaction with users for center file information, the system will ask users to input the incident location on the network by using mouse. Then the system will automatically display the allocation zones in different colors and find a quickest path from all response centers to incident location. In this case, the objective variable of route selection is travel time. So the system will find the quickest path and show them on the screen.

A menu system allows users to reselect routes or view the results again. The graphic display provides a quick and easy way to view the results. A user-friendly interface allows users to easily operate the system and analyze the results.
5. SYSTEM INTERFACES AND SYSTEM STRUCTURE

The design of the routing system involves several basic technical problems such as database creation and database integration, user interfaces, model linkages, route selection implementations, and interactive input and output. Each problem forms a sub-project and deals with system design and implementation issue, which will be discussed in the following sections.

5.1 Database Design and Creation

Basically, the databases needed for routing system include two parts: one is Info data files which are illustrated in the chapter of Network Data Structure and Data Files. The other is Route-System data models which are manipulated by Dynamic Segmentation. Route-systems have the capacity to store information with linear features and help display and analyze the results of network analysis. The event databases linked to route systems manage route information on routes, which is independent of ARC/INFO coverage data model and can be stored in INFO data files or any supported external RDMS.

Therefore, the basic tasks of database design and development include building link data files, adding node information, and creating event databases.
associated with linear features. Link information for our system is obtained from the National Highway Network Coverage (Joy, 1991).

A typical example of link data structure is given as follows:

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FNODE#</td>
<td>18</td>
</tr>
<tr>
<td>TNODE#</td>
<td>19</td>
</tr>
<tr>
<td>LPOLY#</td>
<td>0</td>
</tr>
<tr>
<td>RPOLY#</td>
<td>0</td>
</tr>
<tr>
<td>LENGTH</td>
<td>0.135</td>
</tr>
<tr>
<td>NV-RD#</td>
<td>1</td>
</tr>
<tr>
<td>NV-RD-ID</td>
<td>1E+09</td>
</tr>
<tr>
<td>NAME</td>
<td>I15</td>
</tr>
<tr>
<td>MILES</td>
<td>9.0</td>
</tr>
<tr>
<td>TIME</td>
<td>0.139</td>
</tr>
<tr>
<td>HEADING</td>
<td>S</td>
</tr>
<tr>
<td>URBAN-FLAG</td>
<td></td>
</tr>
<tr>
<td>ONE-WAY</td>
<td>2</td>
</tr>
<tr>
<td>MEDIAN</td>
<td>M</td>
</tr>
<tr>
<td>ACCESS-CONTROL</td>
<td>I</td>
</tr>
<tr>
<td>LANES</td>
<td>4</td>
</tr>
<tr>
<td>TRAF-RESTRICTION</td>
<td></td>
</tr>
<tr>
<td>TOLL-FLAG</td>
<td></td>
</tr>
<tr>
<td>BIT-FIELD</td>
<td>B</td>
</tr>
<tr>
<td>TRUCK-ROUTE-FLAG</td>
<td>2</td>
</tr>
<tr>
<td>BIT1-FIELD</td>
<td>8</td>
</tr>
<tr>
<td>BIT2-FIELD</td>
<td></td>
</tr>
<tr>
<td>PAVEMENT-TYPE</td>
<td>P</td>
</tr>
<tr>
<td>ADMINS-CLASS</td>
<td>I</td>
</tr>
<tr>
<td>FUNCT-CLASS</td>
<td>1</td>
</tr>
<tr>
<td>FUT-FUN-CLASS</td>
<td>O</td>
</tr>
<tr>
<td>STATUS</td>
<td></td>
</tr>
<tr>
<td>A-NODE</td>
<td>1,840</td>
</tr>
<tr>
<td>B-NODE</td>
<td>2,670</td>
</tr>
<tr>
<td>POPDENS</td>
<td>15.349</td>
</tr>
<tr>
<td>RISK</td>
<td>3.7E-04</td>
</tr>
<tr>
<td>ACCIDRATE</td>
<td>2.67E-06</td>
</tr>
<tr>
<td>IMP</td>
<td>0.138</td>
</tr>
</tbody>
</table>
Compared with the data structure shown in earlier, most of the infrastructure data are available. But all environmental data need to be added to the link data files.

The development of a route data model by using Dynamic Segmentation requires significant effort and technical support. Eventually, all network analysis and pathfinding will be built using route systems. Any creation of event databases for linear feature data such as accident data, population distribution, speed zones and etc. has to rely on the existing data files or databases. The pre-processing of the data should be performed according to the requirement of route analysis.

5.2 User-friendly Interface

The essential structure of the routing system is made up of three parts: static routing, dynamic routing, and emergency response. A menu-driven operation system creates a user-friendly operating environment, which is much preferred especially when GIS uses a command-driven format. The format of a menu-driven interface does not require users to memorize commands and parameters. The system lists options of operations in the menu for users to make decisions. A menu-driven system interface will drastically reduce the training time required for using the system.

One feature of the routing system is that users usually deal with spatial data which requires them to construct spatial relationships among information used in the system. Text input and output not only makes the operation difficult, but also takes much time in transferring text data into spatial graphical displays. Thus, routing
procedures in a dynamic setting require a higher degree of interaction between the system and the users.

The routing system in this approach tries to produce a friendly user-machine interactive environment. A graphical display of the study area allows users quickly and visually construct spatial relationships. The system provides users with very flexible graphical input tools by using the mouse to set node points, stops, and centers on screen. Users can also use the mouse to set blocks and barriers on any location shown on the screen. This results in tremendous savings in both preparation time and computation time. User-friendly interface issues are much more important in dynamic routing problems than in static routing problems.

A menu program diagram as shown in figure 5.1 illustrates the logical procedures and menu control processes of static routing, dynamic routing, and emergency routing, which allows users to set the parameters, locate the origin and the destination and display the routing results on the screen.

The implementation of the menu system uses ARC/INFO’s AML language. AML provides the ability to menu-based interface for your application. There are seven different types of menus that can be created in AML: pulldown, sidebar, matrix, form, key, tablet and digitizer. The menu interfaces of the route system described here combine pulldown, form, sidebar and other menu forms. The menu system shown in figure 5.2 is developed in the form of multiple input sources, which enables an application to provide more than one menu or source of commands for the AML processor.
Figure 5.1 ROUTE ANALYSIS GIS PROGRAM MENU
Figure 5.2 The Menu System
The menu interface of the routing system consists of four parts: display field, application field, editing field and dialog field. The display field will display graphical data and routing results such as coverages, routes and selected features, whereas application field includes the options for routing operation of hazardous materials transportation. The application menu supplies a customized front-end for performing feature selection and parameter assignment, and interactive dialog between users and the computer.

The editing field gives users a convenient operating window to perform some basic operations on the coverage, select features and colors, clear window, and zoom in or zoom out. An editing menu may allow users to select, delete and display the routes designated by users. A significant advantage of the editing menu is that it can be used to edit the coverage or routes in real-time, which is very important in routing operations. The dialog field display all the execution information, error messages, and dialog messages on the window. Users can monitor the execution situation of the programs, check the error messages through window. In some cases, the system requires users to answer several simple questions. Thus it is suggested that users should always observe the window to monitor the running process.

5.3 Model Linkages

As the optional part of the routing system, the model linkage interfaces provide the tools for linking the external models or software to the routing system.
The model linkage interfaces allow users to transfer the data files between the routing system and other analysis models to perform specific analysis.

5.3.1 Interface between GIS and Radtran

A GIS and Radtran linkage was developed for estimating risk values based on Info data from GIS and other external data. The data are extracted from GIS and output to an ASCII data file. Fortran programs convert the ASCII output file to a Radtran input deck. Radtran can be accessed via modem to Sandia National Laboratories to perform the desired analysis.

Radtran's output, exposure (in person-rem), is imported into GIS attribute tables. Buffer coverage along various links in GIS is then generated based upon exposure levels obtained from Radtran. After a route is buffered according to the exposure levels, display of the result is available through a customized GIS menu.

5.3.2 Interface between GIS and TRANPLAN

As an alternative way to prepare the spatial data and Info data for GIS coverage, a Tranplan (The Urban Analysis Group, 1992) to GIS linkage was developed for extracting network information from Tranplan.

TRANPLAN, is a computer software which assists a transportation planner in testing land use and network alternatives. The program is separated into more than forty modules or functions, each of which has specific capabilities. Basically, the
typical transportation planning is structured around the following four sequential steps:

a. Trip Generation
b. Trip Distribution
c. Mode Choice
d. Traffic Assignment

A major task of implementation of data transfer is to establish linkage interfaces for transferring the data between different data structures. Figure 5.3 illustrates the interfaces between GIS and Build Network module and Trip Generation module of TRANPLAN.

Similar to a GIS database, a TRANPLAN output data file includes both

Figure 5.3 FLOWCHART OF LINKAGE BETWEEN TRANPLAN AND ARC/INFO
spatial data and tabular data. Consider the output data file from Build Highway Network (HWYNET.DAT) as an example. It contains node data, link data and link info data. Node data has node number and x, y coordinate. Link data has from node number and to node number. Link Info data includes distance, speed, capacity and volume, etc..

Linkage and data transfer include converting data format (e.g. binary, ASCII), extracting data and forming data file for importing to the GIS environment and importing the data. These functions are automated through Fortran programs, GIS AML programs and a series of user commands.
6. ROUTING ANALYSIS AND CASE STUDIES

This chapter will first discuss basic GIS network application tools which may be used for the route system. Next, a demonstration of the system application will be presented by using some case studies based on a highway coverage in Nevada. Routing analysis and the optimization approach are also discussed.

6.1 Network Analysis Tools

The NETWORK analysis tools of ARC/INFO are used to explore the static and dynamic routing processes. There are four sub-modules of NETWORK in GIS. They are Pathfinding, Allocate, Tracing and Spatial interaction. Among them, Pathfinding and Allocate are primary analysis tools for the route system. The Allocate program is used to perform an allocation analysis, such as allocating emergency responders within a certain jurisdictional boundary and constraints. The Pathfinding on the other hand is a program used to determine an optimal path for movement of resources through a network.

To perform the route selection operation, we need to prepare data and set the environment. The work order and basic task of each step are given as follows:
The network coverage must have an AAT. If a stops file is used, the coverage must also have an NAT to refer to stop node locations.

An impedance item must be contained in an AAT, which will be used to calculate the "Cost" for route selections. The stops to be visited are located at nodes. The node locations can be entered interactively or maintained in an INFO file called a "stops" file.

Impedance values to the links may be entered manually or computed by the system automatically.

To set the environment for pathfinding, the network commands use appropriate parameters to indicate data sources, default values and output destinations. The network environment commands include NETCOVER, IMPEDANCE and STOPS.

The above procedures are automated by using AML programs. And impedance values can be calculated according to the optimization function shown in the section of Route System and Data Model. When PATH STOPS is executed, a least-cost path is calculated from a starting point to an ending point, and written to the route-system.

6.2 Editing Menu

The editing menu provides users a very easy way to display, edit and operate the coverage or route systems interactively. It consists of two parts: Coverage Operation and Route System Operation. Before drawing or zooming the coverage,
one needs to first define the feature class, the color and coverage name. The menu system provides a scrolling screen listing the coverage names for easy selections. The button type menu allows users to draw the coverages, zoom, and clean the window.

On the bottom part of the menu, the route system operation menu will help display, delete the route specified. A route system name should be assigned before any operation starts. Figure 6.1 shows an outline of the menu system.

6.3 Static Routing Analysis

The static routing function includes four step processes.

1) Basic Impedance Selection
2) Road Characteristics Selection

3) Risk Factor

4) Pathfinding

These are discussed next.

6.3.1 Basic Impedance Selection

As shown in the figure 6.2, basic impedance selection fulfills the task of assigning weights for Time impedance and Distance impedance.
6.3.2 Road Characteristics Selection

The road characteristic selection menu is designed to consider roadway feature constraints when routing optimization is performed. But at the same time, it may also be used for road feature analysis, functional classification, and pavement analysis. Depending on the data available, it can include as many features as one wishes. In the example used, it consists of five features: one-way or two-way, lanes, median types, pavement types, functional classification (figure 6.3). It is advisable to reset the system (by pushing RESET button) before selecting the features. The button type of feature selection menu enables users to select road features visually and conveniently. The default button is set to ALL. Each time a the selection is computed, the OK button must be pushed in order to execute the selection, and the screen will display the selected area in different colors. Each current selection is based on a previous selected set unless current features have been reset. Thus the selected network is the union of all previously selected sets. Therefore, it is important to note the color changes when each selection is executed. For pavement types and functional classification, different operators may be chosen for the feature selection. The default operator is EQual. Usually, the more features that are selected, the smaller the size of the area for route selections. At this time, it is easy to visually inspect the candidate arc set for future route selections. If the candidate arc set is not big enough, it is possible that there is no feasible solution for route optimization. In that case, it is necessary to loosen the constraints. The initial inspection of the candidate arc set is a crucial step for later risk factor selections and
Figure 6.3 Road Characteristics Menu
path finding. So a suitable candidate arc set will determine the routing results.

Figures 6.4 to 6.7 show the graphical results of each feature selection based on Nevada Highway Network Coverage. Figure 6.7 highlights the rural roads with the pavement type better than 2nd pave, which may be used for case studies.

In order to save the selection results for future editing or dynamic routing, it is essential to assign the route system name and route number. To check current route system status, one may choose LIST ROUTE option which will list all the routes under a specified route name.

6.3.3 Risk Factor Selection

Based on the previous selected set, this function will help to determine a reasonable and acceptable upper risk limit for the route selection. A group of decision-aid tools are developed for determining the risk upper limit (figure 6.8).

The system has functions to perform the statistical operation both on selected network areas and on the designated route. It will display the mean, maximum, minimum of risk values on the selected network area. Users can also browse the risk values on a scrolling screen. After determining the risk limit, users may pre-view the selected results graphically and revise the determinations. The system can also perform the statistical operations on a designated route and display the mean, maximum, minimum of risk values of the route. At the same time, it shows the impedance value (cost) of the route on the screen. So the entire process of decision-making is interactive, transparent and graphical. Both route statistics and network
Figure 6.4 Four Lanes, Divided Highways
Figure 6.5 Functional Classification of Nevada Highways
Pavement Type of Nevada Highway

Figure 6.6 Pavement Type of Nevada Highways
Figure 6.7 Rural Paved Road Network of Nevada
statistics will help users determine the upper risk limit. Based on route statistics of
prior results of route selection, users can adjust the preferences by setting different
risk upper-limit between two objectives: risk limit and impedance (cost). Based on
the results shown in figure 6.7, a group of risk value case studies are performed to
determine a reasonable risk upper limit value. Figure 6.9 shows the road network
with risk value less than 0.4. As we can see, the whole network is broken into pieces.
One can hardly find a continuous route on the network. Figure 6.10 highlights the
roads with risk value less than 11.2 which is also the mean of risk values on the
selected area. They are obviously better than the ones shown in figure 6.9. But there
still exist several broken paths to the destination, which may cause failure in route
selection procedures. After several tests, the discontinuous points are dismissed
Rural Paved Road Network of Nevada
Risk Value Less Than 0.4

ROUTING SYSTEM - CASE STUDY

Figure 6.9 Rural Paved Road Network with Risk Value Less Than 0.4
Rural Paved Road Network of Nevada
Risk Value Less Than 11.4

Figure 6.10 Rural Paved Road Network with Risk Value Less Than 11.4
from the path to the destination, and the upper limit of risk values becomes 45. The road network is shown in figure 6.11.

6.3.4 Path Finding

The major tasks of this function include designation of an origin point and a destination point and executing the Routing Optimization Program (figure 6.12). When the Apply button is pushed, the system will display a subset of network in the yellow color, ready for selecting the origin and destination points. Only those points on the highlighted area in the specified (yellow) color are to be selected. Type "9" when the selection is finished. The system will execute the route selection automatically and display the results in bold red lines. The criteria used for route selection is impedance values on each arc, and a least impedance route is selected. Based on the results of risk upper-limit test shown in figure 6.11, which are also shaded in figure 6.13, the route selection process can be performed. At this point, the route selection processes are pretty simple.

A route selected with UR <= 45, Alpha = 0.3, on rural roads with pavement type better than 2nd Pave is shown in figure 6.13. Fortunately, this route is also a least cost route, which means that this is a optimum route. Another route from the different starting point to the same destination with the same criteria and constraints is shown in figure 6.14. It is a least cost route, but it is not a optimum route. The further discussion continues in next section.
Figure 6.11 Rural Paved Road Network with Risk Value Less Than 45
6.3.5 A Case Study for Route Selection Using Decision-aid Menu

The case study presented in this section will show the procedures to make a decision between the Impedance (cost) and risk upper-limit for route selections. In order to get broad candidate road selections, no roadway characteristics constraints are set. So the entire network's links form the candidate selection set. The basic impedance is set as

\[ \text{IMP} = 0.7 \times \text{TIME} + 0.3 \times \text{DISTANCE} \]

The first step is to select an optimal route (least impedance) from a starting
Route Selection Test 1
Risk Value $\leq 45$
Alpha = 0.3
Rural Paved Road

Figure 6.13 Route Selection Test 1
Route Selection Test 2
Risk Value $\leq 45$
Alpha = 0.3
Rural Paved Road

Figure 6.14 Route Selection Test 2
point to a destination without considering the risk constraints, and perform the required statistical analysis. The route (#10) and statistical results are shown in figure 6.15. Although the maximum risk from Network Statistics is 632.78, the maximum risk from Route Statistics is only 44.085. This implies that the maximum risk upper-limit is 44.085 (URmax = 44.085). The route impedance in this case is 127.14. After several tests, the minimum risk upper-limit is found to be 5.5 (URm = 5.5). Figure 6.16 shows the highlighted roads with risk value less than 5.5. The least impedance route (#11) with risk value less than 5.5 and statistics results are given in figure 6.17. Although the impedance value increases from 127.14 to 149.40 on that route, the maximum risk value decreases significantly from 44.085 to 5.5. A preferable upper-limit UR value can be chosen between 5.5 and 45, i.e.

\[ 5.5 \leq UR \leq 45 \]

Eventually, another route (#12) is found when upper-limit reaches 9.0 (UR = 9.0) which is shown in figure 6.18. The maximum risk is 8.1125, and impedance value is 143.94. The least impedance route is when 5.5 \leq UR \leq 45. A comparison of three routes and statistics is given in figure 6.19. A decision of route selection can be easily made between route 11 and route 12.

6.4 Dynamic Routing Analysis

Figure 6.20 illustrates the major features of the Dynamic Routing function. One of main tasks of dynamic routing is to alter or select a route by referring to real-
Figure 6.15 Route 10 and Statistics with no Risk Constraints
Road Network With
Risk Value Less Than 5.5

Figure 6.16 Road Network with Risk Value Less Than 5.5
Figure 6.17 Route 11 and Statistics with Upper Limit Value 5.5
Figure 6.18 Route 12 and Statistics with Upper Limit Value 9.0
Comparison of Three Routes
With Different Risk Upper Limits

Figure 6.19 Comparison of Three Routes and Statistical data
Dynamic Routing function allows you select or alter the routes according to real events

Selecting Criteria:
- Alpha: 0.3
- One-way: 0
- Pavement: 1
- Lane: 0
- Median: A
- Function: 1
- Risk: 0
- Barrier:

Dynamic Routing Operation
1) Using mouse to set BARRIERS
2) Using mouse to BLOCK roads
3) Selecting the STOPS
   (Start from origin point, and select stops in the order in which the stops will be visited)
4) Executing PATHFINDING

Figure 6.20 Dynamic Routing Menu

time events. Therefore, it is preferable to keep the route selection criteria as much the same as the ones of an existing route as possible. The system can retrieve the information from the previous routing results, display it in both tabular form and graphical form once the route name and route number are entered. Based on that
information, users may alter and select a route by setting barriers, blocking streets, and assigning stop points. Users are instructed to perform the spatial selection interactively by using mouse. It is advisable to observe the dialog window for any messages and answering the questions. The selection of stops should be in the order in which the stops will be visited, i.e., starting from the origin point to the destination point.

6.5 Emergency Response Analysis

Emergency response function is composed of two sub-functions: Allocation and Emergency Response Routing (figure 6.21 and figure 6.22). The basic tasks of allocation is to help people to investigate the distribution of emergency response resources according to the response time constraints. Before the execution of Allocation, Center points which represent the locations of responders must be selected, and a center file which stores the center information should be created. To implement that, users will be asked to select the centers interactively by using mouse and the system will create the center file automatically.

To perform Allocation, the system will ask to enter a route system name for storing the Allocation results and the name of a center file which will be used for Allocation program. The system will then execute the Allocation process and display the results on the display window. Figure 6.23 shows an example with four response centers. The system allocates the zones of distribution for each center within two hours travel time.
Emergency response routing performs the path finding from all response centers to the incident location. The system allows users to enter the incident location interactively and visually by using mouse. It helps not only to locate the closest responder, but also to find the quickest route from the responders to the incident location. This would be greatly helpful for dispatching emergency response vehicles and personnel to the incident location within a shorter time. Figure A.16 illustrates an example of the emergency response routing based on the allocation results in figure 6.24.
Figure 6.21 Emergency Response Allocation

Figure 6.22 Emergency Routing
Allocation Center Test
Maximum Travel Time = 2 hrs

Routing System - Case Study

Figure 6.23 Allocation Center Test
Figure 6.24 Emergency Routing Test
CONCLUSIONS
CONCLUSIONS

The routing system presented in this thesis is developed for a generic analysis of hazardous materials transportation by using GIS. Multi-objective optimization techniques have proved to be effective and useful tools in constructing route optimization models. An improved route optimization model proposed in this thesis is designed to overcome the imbalanced risk distribution on a route, which is ignored in most of the previous approaches. Instead of using absolute risk value in the optimization function, a range risk variable is considered as an objective. This new optimization model, "Range Optimization Model", is adopted as the basis for the development of a routing model. A decision-aid algorithm is developed to help find the optimal solutions or quasi-optimal solutions. The application of the algorithm is demonstrated by using a simplified network in the case studies. The case studies show that the new model not only helps avoid imbalanced risk distribution on a route, but also helps clarify ambiguous interpretation of the optimization results between cost and risk objectives.

The system has been designed to be easy to operate, user-friendly and efficient. ARC/INFO is employed as a major application tool for menu design, database design, data input/output, and optimization implementation. Network
analysis tools and dynamic segmentation of ARC/INFO play a key role in route optimization operations. The system includes static routing, dynamic routing, and emergency response functions. The routing operation function allows users to define problems such as the objectives to be considered, the constraints to be applied, and the way in which risk values are to be estimated.

Extensive effort was devoted to the design and construction of data structures and databases of routing system for hazardous materials transportation. The data structure of the system includes pre-set data files such as link data files and on-line created data files (dynamic data files) such as stop files and center files.

For the purpose of case studies, data related to accident rates and travel time were simplified based on reasonable assumptions. A simplified Nevada highway network with hypothetical attribute values was developed for model tests and application analysis.

The GIS-based routing system developed in this thesis facilitates the automation of route selection, feature selections, real-time route edits, emergency response analyses, and interactive interfaces. This prototype routing system could lead to the development in new ways and different application tools for routing analysis as well as for the study of hazardous materials transportation. Future perspectives based on this approach or related to this study may include:

- The model developed in this thesis utilizes risk values as key inputs. The current effort did not address the development of methodologies or techniques to quantify and estimate risk. It is to be realized that significant
efforts are necessary to improve the state-of-the-art of the techniques used to estimate risk. This is indeed a topic that is worthy of future research efforts.

. Developing the algorithm and implementing the optimization operation for the routing problems involving risk factors

. Developing accident rate event databases, traffic volume event databases, and creating corresponding route-systems using dynamic segmentation functions.

. Enhancing and perfecting the routing system, adding more features and selection criteria such as time-dependent routing, weather considerations, hazardous materials siting.
APPENDIX  Major AML Programs for Routing System Menu

/* Main Menu */

&term 9999
&s .temp1 = = '
&s .temp2 = ,
&s .cover = hazmat
&s .alpha = 0
&s .onew = 0
&s .func = 0
&s .lane = 0
&s .pave = 0
&s .med = A
&s .opt1 = eq
&s .opt2 = eq
&s .risk = 0
display 9999 size 775 622 pos 500 400
&echo &on
&thread &create 'HAZMAT ROUTING SYSTEM' &menu applicat.menu &size ~ 775 100 &pos &above &display
&thread &create 'Editing Menu' &menu projs.menu &size 420 722 ~
&pos &left &thread 'HAZMAT ROUTING SYSTEM'
&thread &delete &self

/* Hazmat Application Menu */

1 ROUTE ANALYSIS GIS PROGRAM
'STATIC ROUTE'
'Basic Impedance' &menu bi.menu
'Road Characteristics' &menu road.menu
'Risk Factor' &menu risk.menu
'Pathfinding' &menu path.menu

96
'DYNAMIC ROUTE' &menu dynam.menu
EMERGENCY
Allocate &menu allocat.menu
'Emergency Routing' &menu emerg.menu
QUIT

/****************************
/* Editing Menu     *
/****************************

7 input coverage
COVERAGE OPERATION

Feature Class
%2
Enter Color #
%3
Input Coverage
%1    %clear
     %cancel
     %help
     %ok
     %zoom
     %patch

-- Plot Map
Plot file name %pname
   %start   %end

ROUTE SYSTEM OPERATION

Enter Route Name: %ratname
Enter color #:  %color
Select Route:  %rat
   %display
   %delete
   %reset
%1 input .incov 12 typein yes scroll yes rows 4 ~
   required cover * -all 'select a coverage'
%2 choice .feat pairs LINE arcs POLY polygons POINT nodes
%3 input .covcol 2 integer
/*build %incov% %feat% */ap;disp 9999;mape %incov%;~
/*arcs %incove%;&return
%help button return keep 'HELP' help
%ok button DRAW mape %.incov%;linecolor %.covcol%;arcs %.incov%
%zoom button REDRAW linecolor %.covcol%;arcs %.incov%
%patch button PATCH shadesymbol 1;patch *
%ratname input .ratn 10 character
%color input .color 2 integer
%rat input .ratid 10 scroll yes rows 3 typein yes unique ~
%.incov%.rat%.ratn% -info %.ratn%-id
&display button Display &r selrat
/*sel %incov% route.%ratn% name = '%ratid%';routelines %incov% %ratn%
%color%
%delete button Delete &r delrout.aml
%reset button Reset cleasel
%pname input .pname 8 character
%start button START map %.pname%;&r yplot
%end button END map end
%cancel button cancel 'CANCEL' &return
%clear button 'Clear Window' clear
/*%ratname input ratn 10

/****************************
/* Basic Impedance Menu   *
/****************************

7 static routing menu
Select Basic Impedance

%1   Travel Time
%2   Distance
Both, then input the weight for distance: %3

%ok  %help  %cancel
%1 button 'Travel Time' &sv .alpha = 1
%2 button Distance &sv .alpha = 0
%3 input .alpha 8 real

/****************************
/* Road Characteristics Menu *
/****************************

7 road characteristics
ROAD CHARACTERISTICS SELECTION MENU
Please push button OK after each selection

1) %1 %ok0
2) %3 %ok2
3) %4 %ok3
4) PAVEMENT TYPE %5 %ok4
5) FUNC-CLASS(1-19) %2%ok1
    OPERATOR %opt
%reset %cancel

If you want to save the selections, please enter:
Enter Route Name: %ratname
Enter Route #: %ratnum

%save %list

%1 choice .onew pairs ALL 0 ONEWAY 1 TWOWAY 2
%ok0 button Ok &r onew.aml
%2 input .func 2 integer
%3 choice .lane pairs ALL 0 2-LANE 2 4-LANE 4
%opt choice .opt pairs EQ eq LOW ge HIGH le
%ok1 button OK &r func.aml
%ok2 button OK &r lane.aml
%4 choice .med pairs ALL A DIVIDED M UNDIVIDED C FERRY F
%ok3 button OK &r med.aml
%5 choice .pave pairs ALL 0 PAVE 1 '2nd PAVE' 2 GRAVEL 3 DIRT 4 FERRY
%ok4 button OK &r pave.aml
%reset button RESET clearsel
%ratname input .ratname 10 character
%ratnum input .ratnum 5 integer
%save button SAVE &r saverd.aml
%list button 'LIST ROUTE' &r listrat.aml
%cancel button Cancel 'CANCEL'&return
%forminit &s opt = eq;&s .opt1 = eq;&s .opt2 = eq
%ok button OK &r bi.aml
%help button return keep 'HELP' help
%cancel button cancel 'CANCEL'&return
/* Risk Factor Menu */

7 risk factor selection menu

DECISION-AID MENU OF RISK FACTOR DETERMINATION

Please enter:
Route Name: %ratname Route #: %ratnum
  %rstat
Max Risk: %rmax
Min:   %rmin
Mean:  %rmean
Impedance: %rimp
  %stat   Risk Value:%risk
Max Risk: %max
Min:   %min
Mean:  %mean

%preview %reset %apply %save %exit

%ratname input .ratname 10 character
%ratnum input .ratnum 5 intege
%stat button 'NETWORK STATISTICS' &r statist.aml
%max display .max 6 value
%min display .min 6 value
%mean display .mean 6 value
%rmax button 'ROUTE STATISTICS' &r rstatist.aml
%rmax display .rmax 6 value
%rmin display .rmin 6 value
%rmean display .rmean 6 value
%rimp display .rimp 6 value
%preview button PREVIEW linecolor 6;arcs %.cover%
%reset button RESET &r reset.aml
%apply button APPLY &r risk.aml
%save button SAVE &r savebd.aml
%risk input .risk 10 scroll yes rows 5 typein yes unique ~
  %.cover%.aat -info risk real
%exit button EXIT 'CANCEL'&retum
7 this programs perform pathfinding task

Please Assign:

Route System Name: %1
Route Number : %2

%apply %list %cancel
%1 input .ratname 10 character
%2 input .ratnum 5 integer
%apply button help 'Select the starting & destination points using ~
mouse, then press 9' APPLY &r selpath
%list button 'LIST ROUTE' &r listrat.am1
%cancel button Cancel 'CANCEL'&return

/* Dynamic Routing Menu */

7 dynamic routing

DYNAMIC ROUTTING
Dynamic Routing function allows you select
or alter the routes according to real events
Please enter:
Route Name: %ratname Route #: %ratnum %ok
Selecting Criteria:
Alpha:%6 Oneway:%2 Pavement:%9 %4 %cancel
Lanes:%3 Median:%5 Funclas:%10 %6
Risk: %11 Barrierfile:%7 Stopfile:%8 %draw

DYNAMIC ROUTING OPERATION
1) Using mouse to set BARRIERS %app1
2) Using mouse to BLOCK roads %app2
3) Selecting the STOPS %app3
   (Start from origin point, and select stops in
   the order in which the stops will be visited)
4) Executing PATHFINDING %app4

%draw button 'DRAW ROUTE' linecolor 2;
resel %.cover% route%.ratname% %.ratname%-id = %.ratnum%;
routelines %.cover% %.ratname% 2
%ok button OK &r readdrd.am1
7 Allocate Emergency Responders

EMERGENCY RESPONDER ALLOCATION
This module will allocate the responders according to response time

Please enter:
Allocation system name:%1
Maximum response time :%2
7 emergency routing

**EMERGENCY ROUTING**

This module will find the routes from the responders to the incident location.

Please enter:
Allocation system name: %1
Route system name : %2

%view %incid %list %rout %exit

%1 input .alcname 8 character
%2 input .emergrat 8 character
%view button 'View Centers' &view.aml
%list button 'List Centers' &r listcnt.aml
%incid button 'Enter Incident Location' &r selinc.aml
%rout button Routing &r emergrout.aml
%exit button Cancel 'CANCEL' &return
BIBLIOGRAPHY


