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16. Abstract

The Motor Carrier Division (MCD) of the Texas Department of Transportation (TxDOT) typically issues more than 45,000 permits each month for oversize and/or overweight vehicles. The current procedure for attending permit requests for superheavy vehicles is entirely manual and requires hundreds of man-hours. This report documents the efforts to implement a procedure for the automated route evaluation for overweight/oversize vehicles. The procedure uses a network representation of the On-system roads according to TxDOT base maps to identify bridges on the vehicle's route. The bridges' adequacy, in terms of clearances and weight restrictions, are evaluated. The weight capacities of the bridges are determined according to Texas Administrative Code requirements and/or through Bridge Load Formulae. Description of the operation of the system for routing, as well as for bridge management applications are included.

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Automated Route Evaluation of Overweight/Oversize Vehicles

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NOT INTENDED FOR CONSTRUCTION, BIDDING, OR PERMIT PURPOSES

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ABSTRACT

The Motor Carrier Division (MCD) of the Texas Department of Transportation (TxDOT) typically issues more than 45,000 permits each month for oversize and/or overweight vehicles. The current procedure for attending permit requests for superheavy vehicles is entirely manual and requires hundreds of man-hours. This report documents the efforts to implement a procedure for the automated route evaluation for overweight/oversize vehicles. The procedure uses a network representation of the On-system roads according to TxDOT base maps to identify bridges on the vehicle's route. The bridges' adequacy, in terms of clearances and weight restrictions, are evaluated. The weight capacities of the bridges are determined according to Texas Administrative Code requirements and/or through Bridge Load Formulae. Description of the operation of the system for routing, as well as for bridge management applications are included.

EXECUTIVE SUMMARY

The objective of this project was to develop an automatic procedure for evaluating the adequacy of bridges along routes for overweight/oversize vehicles. The procedure developed uses a network representation of the On-system roads to identify inadequate bridges in the vehicle's route. The network model is included within a Geographic Information System operating in the PC environment. The model was based on the On-system roadways and simulates the travel of vehicles within the On-system highways only. The system automatically finds a shortest path between an origin and a destination disabling segments with inadequate bridges due to capacity or clearances for a given overload/oversize vehicle. The system, however, only responds to the information that is included within the GIS and does not consider other routing factors such as construction activities, roadway obstructions and others.

The overweight vehicle is first analyzed according to the Texas Administrative Code requirements. If the vehicle fails to meet these requirements, then the determination of a route is performed evaluating the bridges using the Bridge Load Formulae and the rating and description parameters included in BRINSAP. Since the system links to BRINSAP through the bridge identification, the future incorporation of PONTIS will allow a more accurate bridge evaluation without the need of empirical formulae. The efforts of this project focused on implementing an operational system that addresses the routing process of superheavy loads.

In addition to routing, the system has important uses in bridge management. The system is capable of displaying bridge location according to the information in the BRINSAP database. This has provided the TxDOT Design Division with the capability of quickly producing bridge location maps according to desired attributes.

This report includes:
(1) A summary of the work accomplished under the different tasks of the project.
(2) A description of the operation of the GIS system to route overweight/oversize vehicles.
(3) A description of three proposed modifications to enhance the routing software to consider or improve the avoidance of U-turns, the computational procedure to evaluate bridges, and sorting of bridges on the basis of rating and the longest span length. And
(4) Illustration of bridge management applications of the system.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The Motor Carrier Division (MCD) of the Texas Department of Transportation (TxDOT) is in charge of issuing permits for overload and overweight vehicles for the state highways under its jurisdiction. These are referred to as the On-system highways. With the continuing increase in commerce and trade in Texas, the MCD has experience an increase in the number of permits issued for oversize and overweight vehicles from about 35,000 to about 45,000 permits per month in a period of two years. The volume of permit request is expected to continue increasing.

Some of the permit requests are for super heavy loads, which can be defined as those vehicles in excess of 300,000 pounds. Figure 1.1 shows pictures of some of these vehicles. The current procedure for processing requests for this type of vehicles is time consuming and costly. The process consists of (a) the establishment of a tentative route with adequate width and height clearances, (b) an identification of all the bridges along the route, (c) the retrieval of information pertaining to the bridges to be crossed, and (d) a structural analysis of critical bridges, performed in the Design Division of TxDOT, to evaluate their adequacy for the vehicle. If a structure is not adequate, an alternate route is investigated. Furthermore, for the purpose of reducing the permit processing time, it is also customary to re-use portions of routes already analyzed for greater loads. This approach, however, may create future problems because the same bridges are subjected to repeated overloads.

1.2   Background

1.2.1 Current Permitting Procedure

In May 1991, the Texas Legislature adopted into the Texas Administrative Code [1] (TAC) the method currently used by the MCD to analyze most overweight permit requests. These regulations limit the axle weights by two methods. The first method imposes a gross weight limit on axle groups which depends on the number of axles in each group, as well as imposing a limit on the tire loads; this limit is 650 lb/in. of tire width. If either the axle group weight or the tire load are exceeded, a permit may still be issued under the second method, the Equivalent Distributed Load (EDL) method.

The EDL method allows consideration of factors that provide greater distribution of the axle group's weight. These factors are the number of tires, gage distance and longitudinal distribution of the load by the deck. In essence, the EDL method converts the axle group weights to an equivalent distributed load which is then compared to the maximum allowed for the corresponding wheelbase. If the EDL of the axle group is less than the maximum allowed, then the MCD will issue the permit. However, if the permit is denied, TxDOT's Design Division performs an analysis of the bridges along the vehicle's route to determine if a permit may still be issued.

Figure 1.1. Examples of Superheavy Vehicles in Texas On-System Highways.

On one hand, the major drawback of the procedure adopted into the TAC [1] is that it does not consider the fact that the resulting forces in a bridge are not only dependent on axle weights, wheel base and gage but also on the geometry and the material properties of the bridge. On the other hand, the significant drawback of analyzing each bridge on the vehicle's route is that the procedure is time consuming and costly.

1.2.2 Previous TxDOT Projects

To address the problems mentioned above, TxDOT initiated and completed Projects 1266 and 1443 to develop general formulae and procedures for issuing the permits passing over Texas' On-system bridges and to demonstrate the feasibility of an automatic routing procedure. The procedural direction of these projects were dictated in part by the information contained in BRINSAP. In project 1266 [2], the Texas Transportation Institute (TTI) developed formulae for limiting group weights passing over H15, H20 and HS20 simple span bridges. Two types of bridge formulae were developed for each bridge type, a general formula and a bridge-specific formula.

Also in Project 1266, the feasibility of an automatic routing procedure through the use of a network flow model of the On-system roads of TxDOT's Houston District that identifies all bridges along a route [3,4] was demonstrated. The network model was developed from digitized geographic drawings available in TxDOT's Transportation Planning and Management Division (TPP). The drawings were used to define nodes (intersections) and arcs or links (segments of roads). For the purpose of routing vehicles, the nodes and links were given attributes such as intersecting highways, highway types and numbers, lengths, coordinates, etc. For the purpose of identifying the bridges to be crossed, the bridge identifications were attributed to the nodes and links.

As a continuation, Project 1443 defined permit bridge load formulae applicable to bridges designed for the AASHTO H-type and HS-type axle configurations [5]. These efforts not only included formulae for the four design types (H15, H20, HS 15 and HS20) but also formulae for bridges which may have been designed by or reduced to another HX or HSX designation. Two types of formulae were derived for the HX and HSX axle configurations, a general formula, function of the vehicle configuration, and a bridge-specific formula that is also a function of the span length [5]. The first formula has two important uses: (1) given the vehicle's axle configuration and the bridge design type, it can calculate the maximum allowable load for any HX or HSX bridge, and (2) given the axle group and the total load, the formula can convert the vehicle's load to an equivalent load of a HX or HSX AASHTO truck. The first use offers the advantage that the differences between the allowable load (resistance) and the actual load (load) (always positive) can be used as a margin of safety parameter to determine an optimal route. This optimal route may be defined as a short route (not necessarily the shortest) that may minimize not only the number of bridges to be crossed but also may maximize the margin of safety. These problems are normally solved using network optimization techniques. In the second use, by converting the actual vehicle to an equivalent HX or HSX status, the BRINSAP records of the operating and inventory ratings of the bridges along a route can be accessed to quickly assess the adequacy of the bridge structure for the given truck. Furthermore, the route optimization

problem can now be defined by maximizing the ratio of the operating or inventory rating to the equivalent HX or HSX status.

The two types of uses previously described can be implemented in an automated route evaluation system since all non-posted bridges in BRINSAP have inventory and operating ratings based on H- or HS-type vehicles.

The bridge-specific formula developed under Project 1443 is a function of the span length and cannot be fully implemented due to the lack of complete span lengths in BRINSAP. However, this formula is more accurate and allows for the greatest allowable loads. At the present this formula cannot be implemented for all the On-system bridges, it can only be applied to single-span and two-span bridges. BRINSAP records currently include the total length of the bridge as well as the largest span length.

1.2.3 PONTIS

TxDOT is in the process of implementing PONTIS, a federally-funded Bridge Management System designed to aid DOT agencies in the more sophisticated procedures for managing bridges. By using state-of-the-art modeling techniques and optimization procedures and a detailed bridge database, PONTIS can predict bridge deterioration, find cost effective actions to correct problems, select appropriate bridges for improvement and replacement and help in the scheduling of work. PONTIS also utilizes a new bridge description and condition rating system that is more detailed than the existing system which is based on bridge inspections. The PONTIS bridge database will be more detailed than BRINSAP and will be able to provide for a more effective bridge evaluation system. This future database will offer the advantage that the evaluation of an individual bridge for a given vehicle could be performed directly considering the vehicle characteristics and the bridge's geometric and materials properties included in the database, without the use of any empirical formula. AASHTO analysis procedures or even finite element analysis could be performed automatically. This would permit a more accurate and less conservative approach for the issuing of overload permits.

1.2.4 Geographic Information Systems and Digitized maps

Several Geographic Information Systems (GIS) are now available for all types of computer systems. Powerful GIS systems can now be implemented in the PC environment at relatively low cost. GIS are programmable software packages that assist in the management of geographic information. All GIS packages employ digitized drawings (maps) and relational databases associated with the drawings. They typically include different modules to make the GIS perform desired actions, as well as programmable features that allow users to customize the GIS for a given application. These features make the GIS attractive for the purpose of routing overweight vehicles. First, the basis of the GIS would be digitized maps of the On-system roadways. The network-flow models can be built into the GIS by defining the nodes and arcs (links) and their corresponding attributes (highway identifications, directions, highway types, length, etc.). The On-system bridges can be correctly located and incorporated into the GIS along with their identifications that provides accesses to BRINSAP (or PONTIS in the future) and the bridge

attributes. More importantly, it allows access to inventory or operational bridge ratings that are needed for evaluating bridge load formulae to determine the adequacy of the structure for an incoming overload.

1.3 Objective

The objective of this project was to develop an automatic procedure for evaluating the adequacy of bridges along routes of overweight vehicles. The procedure developed uses a network representation of the On-system roads to identify critical bridges in the overweight vehicle's route. The network model is included within a Geographic Information System operating in the PC environment. The model was based on the On-system roadways and simulates the travel of overweight vehicles within the On-system highways only. The system automatically finds a shortest path between an origin and a destination disabling segments with inadequate bridges due to capacity or clearances for a given overload/oversize vehicle. The system, however, only responds to the information that is included within the GIS and does not consider other routing factors such as construction activities, roadway obstructions and others.

The overweight vehicle is first analyzed according to the TAC requirements described in Section 1.2.1 of this report. If the vehicle fails to meet the TAC requirements, then the determination of a route is performed by evaluating the bridges using the Bridge Load Formulae and, the rating and description parameters included in BRINSAP. Since the system already links to BRINSAP through the bridge identification, the future incorporation of PONTIS will allow a more accurate bridge evaluation without the need of empirical formulae. The efforts of this project focused on implementing an operational system that addresses the aspects of routing superheavy vehicles. The system has been developed for TxDOT's Houston District and is being expanded.

In addition to routing, the system developed has found important uses in the area of Bridge Management. Because the routing system requires the geographic definition of the bridge locations and access to their attributes stored in BRINSAP, the GIS system is capable of displaying bridge locations according to the information in the database. This has provided TxDOT's Design Division with the capability of quickly producing bridge location maps according to values in the BRINSAP records.

CHAPTER 2

SUMMARY OF WORK ACCOMPLISHED

To fulfill the objectives of the project, nine tasks were performed. This chapter contains a summary of the work accomplished according to tasks originally defined in the work plan.

2.1 Survey of GIS and CAD software, Databases and Routing Methodologies

This initial task consisted of a survey of GIS and CAD software packages that are in use in TxDOT, a survey of the data structure of the BRINSAP and PONTIS, and an investigation of network modeling methodologies. Details of the results of this task were reported in Ref. [6] and a summary is presented here. The survey of the GIS and CAD software had the purpose to make an intelligent decision on the particulars of the GIS system to be used in the project. The researchers selected to use TransCAD GIS software for its easy implementation in transportation routing problems. The reasons for the selection were based on: a) handling of grade separation, b) user-friendliness, and c) versatility to customize for the particular routing application. This decision also simplified the handling of network routing methodologies since they were already included within the software.

In addition, other critical decisions were made related to this task.

1) Use TxDOT maps available from the Graphic Office of the Transportation Planning Division (TPP). The main reason was that these maps are the most complete drawings currently available, containing the geometric characteristics of overpasses, underpasses, interchanges and exit ramps. These features were critical to develop an accurate representation of the On-system roads and the location of the bridges.
2) Use TxDOT's roads database being developed. This decision was made because it is expected that this will become the official road database. In addition, the database is expected to grow with time.
3) Use BRINSAP database. BRINSAP is the only bridge database currently available. Since PONTIS is still under development it could not be used. Provisions were made that allow the merging of future bridge databases with the routing system.

2.2 Generation of Routing Model

In this task we developed procedures for the development of network models from the TxDOT base maps. The results of this task were comprehensively reported in Ref. [6]. The generation of the network model was accomplished in such a way as to maintain an accurate inventory and description of the roads. For this reason, TxDOT TPP's Intergraph base maps were used instead of USGS maps. Besides their superior scale and level of detail, TPP's maps have a road information database attached to the maps that it is expected to grow and be maintained by TxDOT as the official database. In addition, TPP's maps are the only ones that contain the details of intersections, interchanges and exit ramps, that are critical for accurate routing. The base maps and their databases were converted to the GIS system. However, TPP's files required

a significant amount of cleaning to convert them to network models. Typical problems included: a) connectivity problems, b) extra line problems, c) duplicate lines and d) small length elements. These problems were corrected semi-manually using a computer-assisted procedure. Once these problems were eliminated, the definition of the network required the assignment of overpasses, underpasses, one-way directional links, and attributing the road information data from the centerline to the adjacent divided highways. Figure 2.1 shows an interchange showing the assignments of overpasses, underpasses, and unidirectional road segments. As it can be appreciated, this process of creating an accurate network was time consuming. It was completed for the Houston District. The advantage of the approach taken is that TxDOT will be able to update and maintain the system because TxDOT base maps and databases were used. For a more detail description of the procedures for generating the network models, see Chapter 4 of Ref. [6].
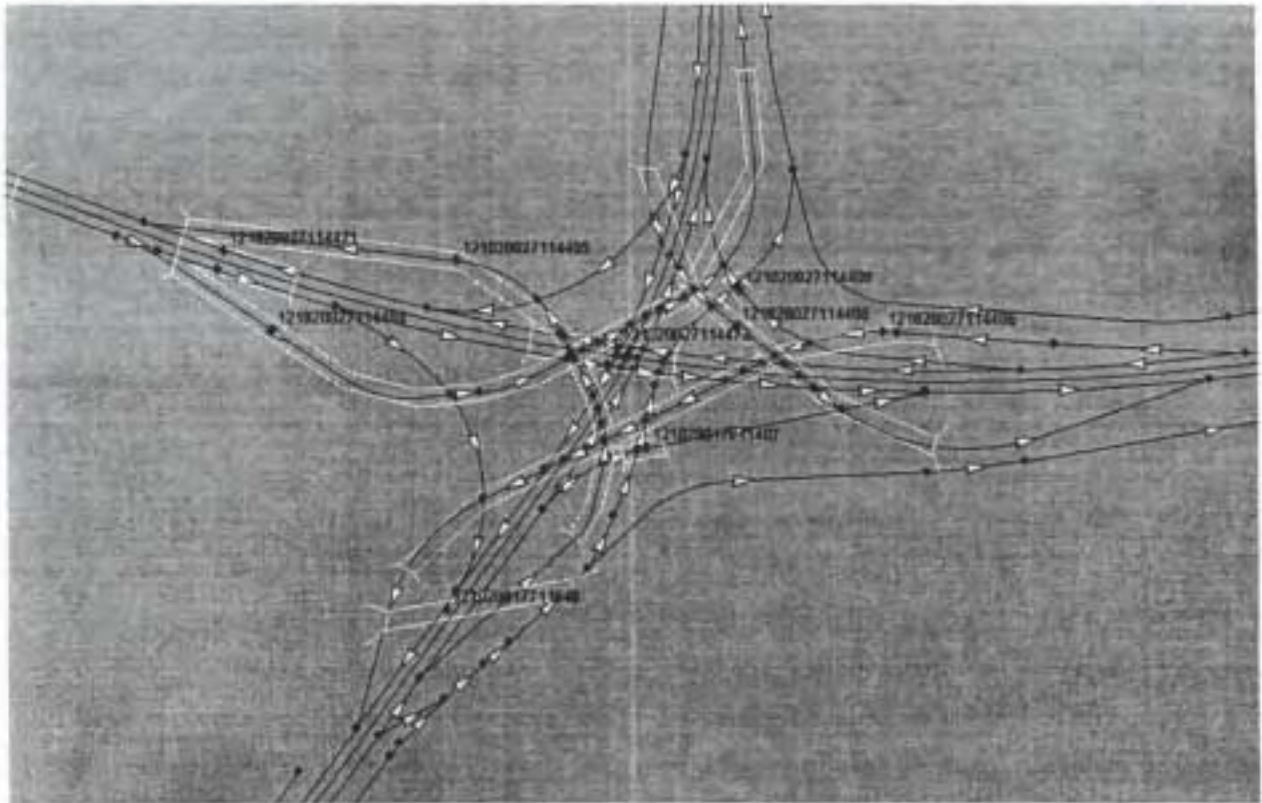
Figure 2.1. An Interchange Showing the Assignment of Overpasses, Underpasses and Direction of One-Way Road Segments.

2.3 Identification of Bridge Locations

On of the most critical elements of the functionality of the routing model is to have the correct bridge location with its proper identification. That is, the bridge identification needs to be attributed to the links or segment of roads of the network model. To accomplish this task, the following information was available: (a) longitude and latitude coordinates of BRINSAP, (b) bridge symbols indicating the presence of bridges on the road, (c) BRINSAP information such as facility carried over, feature crossed, description of location and direction of travel, (d) printed maps indicating the bridge identification at the correct location, and (e) TxDOT urban files that contain the names of all on-system and off-system roads and other geographic features such as rivers, railroad crossings, creeks, etc.

The following problems existed in the identification process:
(1) The geographic coordinates stored in BRINSAP are not accurate.
(2) The geographic coordinates for some bridges were missing coordinates.
(3) The BRINSAP's description of location, facility carried over, and the feature crossed was incorrect for some bridges.
(4) The TxDOT base maps showed bridge symbols at locations where there was no bridge and the bridge symbols were also missing for some bridges.

In this task a very effective procedure to correct the bridge longitude/latitude coordinates stored in BRINSAP was developed. The geographic coordinates coded in BRINSAP were used to create points on the GIS system indicating the potential location of the bridges. The On-system roads and the bridge symbols included in the geographically accurate TxDOT's urban files were also imported to the GIS system. By overlaying the BRINSAP points and the roads and bridge symbols, the inaccuracies in the BRINSAP coordinates were obvious because the points and the symbols usually did not coincide. The following procedure for correcting the coordinates was used: 1) Every bridge in a county was considered one at a time. 2) Its location was first checked in printed maps that were provided by TxDOT's Design Division. 3) The information that provides the description and location of the bridge, such as feature crossed, facility carried over, location description, etc. was revised. 4) The correct location was then found in the GIS maps, and the point corresponding to the bridge was moved to its correct location, automatically providing accurate longitude/latitude coordinates that were updated. For most bridges, the above procedure was sufficient to correctly locate them. However, for those bridges with missing bridge symbols, without coordinates, or in complicated interchanges, individual attention was required in the localization process. This process was very safe, however, it was time consuming. On the average, it took about one man-hour to correct the location of seven bridges.

Figure 2.2 illustrates a complicated interchange with the bridge locations before and after the correction process. The bridge labels were omitted from this figure for clarity purposes.
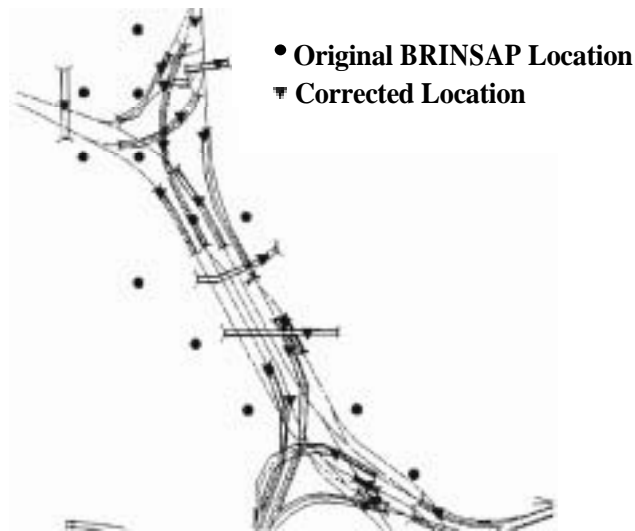
Figure 2.2 Correction of BRINSAP Coordinates in a Highway Interchange.

The completion of this task demonstrated two major benefits for TxDOT: 1) a link was created between the BRINSAP data and the bridge locations on the base maps. This was performed by a clever utilization of the BRINSAP latitude / longitude and other BRINSAP data without the use of GPS receivers; and 2) by correcting BRINSAP longitude/latitude coordinates and merging BRINSAP to a GIS system, capabilities were developed to quickly display bridges as function of their attributes.

During the activities undertaken for the correction of bridge location, the general observations on the bridge locations were meticulously documented. The observations were compiled in files containing information pertaining to the identification and location of each bridge. The error reports include the bridge identification (in ascending order), the BRINSAP Structure number, the check status (C for "checked" or E for "error"), observations or comments regarding its location status, feature carried over, location description, original longitude and latitude coordinates and the updated or modified coordinates. The bridge correction was completed for 7 Texas Districts (Austin, Beaumont, Bryan, Houston, Lufkin, Waco and Yoakum). When the project terminated, the correction of the bridges in Dallas, Fort Worth and Tyler districts were in progress. Figure **2.3** illustrates the coverage of the bridge location correction. Appendices **A** through G include the bridge observation reports for the completed Districts.

2.4 Bridge Evaluation Methodologies

This task consisted of the implementation of the bridge evaluation methodologies. There are several formulae that could be implemented to evaluate the adequacy of the bridge structures for the incoming vehicles. The formulae are functions of the vehicle characteristics as well as the bridge ratings. This task was reported in Ref. [6]. The system developed considers both, the Texas Administrative Code procedure and the Bridge Load Formulae. Both, the general and the bridge specific formulae are used depending on the data available in BRINSAP. In the individual

span lengths can be extracted, then, the bridge specific formulae are evaluated, otherwise the general formulae are used. The methodology considers the critical combination of axle groups for the particular bridge or bridge span.
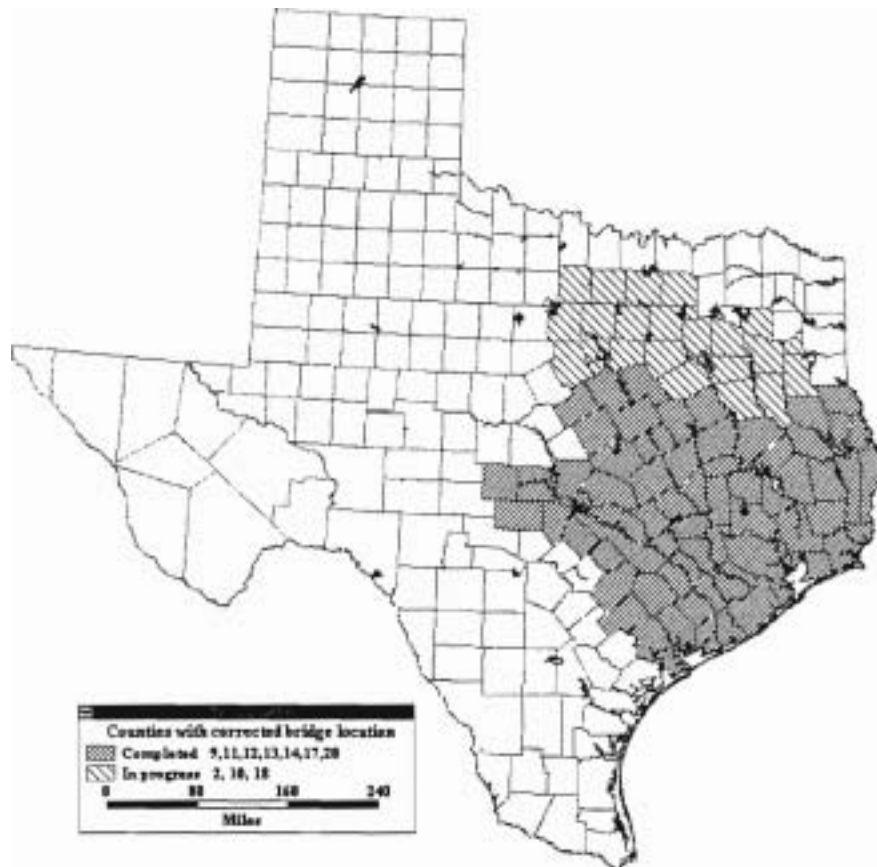
Figure 2.3 Coverage of Bridge Location Corrections.

2.5 Incorporation of Physical Road Constraints

The MCD already has a mechanism of compiling all the road constraints and the road maintenance activities. The possibility of including a module in the network model to consider a dynamic system of managing constraints in the roads was investigated. However, it was realized that the volume of information to be acquired was enormous and beyond the scope of this project. Nevertheless, because BRINSAP records contain the minimum vertical clearance on and underneath the bridge, this information was linked to the road segments of the network. The height and width of the vehicle are always checked against the bridge's minimum underneath vertical clearance and deck width, respectively. If a road segment has a minimum vertical clearance less than the vehicle's height, then the segment of road is disabled from the network. Similarly, if the deck width is less that the vehicle width, the road segment is also disabled.

2.6 Incorporation of Optimization Models

The overweight/oversize vehicle routing system currently solves the routing problem by finding the Shortest Path route between a given origin and destination. The Shortest Path algorithm was available as a built-in function of TransCad's GIS macro language and was incorporated into the program code specifically customized for this project. The Shortest Path algorithm is documented in Chapter 5 of Ref [6]. The algorithm also allows for the definition of intermediate stopping points. This feature allows for the semi-manual definition of routes. Provisions were made to incorporate a Maximum Capacity route algorithm developed by TTI.

2.7 Computerization & Demonstration

This task consisted of the compilation of all the different modules of the automated routing system of oversize/overweight vehicles. The computerization of all the modules was done within the GIS software and is self contained. Demonstrations of the package were performed in several occasions to MCD and the Design Division of TxDOT. Some of these include TxDOT's Innovation Showcase, held in College Station, TX. in October 1996 and in the RMC 4 meeting at Corpus Christi in December 1996. The latest demonstration was done in TxDOT's TP&D Conference in June 1997.

2.8 Validation

This task consisted of a compilation of some of the historical records of the routes certain overweight vehicles have followed and whose permits were issued by MCD. The compilation aimed at identifying cases of superheavy loads were a significant amount of engineering analysis was required. The fundamental idea behind this task was to validate not only the network routing optimization package but also the bridge evaluation procedure. The adequacy of the model has not yet been validated by determining how well it predicts the effect of the relevant decisions made by the computerized system, since the most of the compiled cases are out of the scope of the present working network area (Houston District).

2.9 Improvements in the Routing Model

The purpose of this task was to make the routing of overweight or oversized vehicles more realistic for the MCD permitting office to be able to issue permits in an effective and efficient manner. The running version of the software is described in the next chapter. Some modifications were explored and are documented in Chapter 4.

CHAPTER 3

OVERWEIGHT/OVERSIZE VEHICLE ROUTING PROGRAM

3.1 Summary

This chapter consists of a description of the current GIs-based overweight/oversize vehicle routing program. The program has been incorporated within the TransCAD GIS software. It consists of a network representation of the On-system highways according to TxDOT's official base maps. The links of the network are interconnected to simulate allowable traffic flows and represent an accurate model of interchanges, overpasses and underpasses. The TxDOT's roads database, originally assigned to the centerlines, has been used to build the attributes of the road segments. The corrected locations of the BRINSAP's bridge geographic coordinates were used to attribute the bridge identifications to the corresponding links (representing road segment) that the bridges are located on. This permits the identification of bridges along routes and the access to the BRINSAP records as a function of the traveled route. The routing model was incorporated as a macro within the software. The user specifies the characteristics of the vehicle, to include weight and dimensions, and the program finds a shortest-path route bypassing bridges with insufficient clearances or weight capacity, according to the TAC requirements and/or TTI's Bride Load Formulae. This chapter includes a description of the software.

3.2 Software Overview

In order to execute the routing software, the program requires (a) a commercial license of the TransCad GIS software, (b) a GIS map containing a three layers (Roads, BRINSAP, and Endpoints) and (c) an existing road network file created from the ROADS layer, including all links and endpoint information. The GIS map includes (1) the Roads layer which defines the On-system highway network with an associated roads database, (2) the BRINSAP layer providing access to the records of the On-system bridges, and (3) the Endpoints layer which define the nodes and links in the road layer. The Endpoints also correspond to the origin and destination points of travels. To properly execute the software, it is necessary first to become familiar with where the required files are located. The locations of the files are indicated below.

Type of Files	Location
GIS maps	D:\mergetx\networks*.map
Network files	D:\mergetx\networks*.net
Roads layer	D:\mergetx\roads*.cdf or *.dbd
BRINSAP layer	D:\mergetx\BRINSAP*.cdf or *.dbd
Endpoints layer	D:\mergetx\roads*.pts
Vehicle Description (Input files)	D:\mergetx\veh_lib*.veh
Output Routing reports	D:\mergetx\reports*.out
Help files	D:\macros\helpovr.txt
OVR macro program	C:\tcw\ovr.rsc

3.3 Opening and Running the Routing Program

First, Open TransCad from the Desktop or the Start programs menu. Once in TransCAD open the GIS map file associated with the desired Texas On-system highway network. These files have the extension of *.map. By opening the "map" file, the software automatically loads the files associated with the geographic features of the maps. That is, the roads, BRINSAP and the endpoints.

To invoke the routing program, from the software select "tools" and "Add-Ins.." and then select the "Overweight Vehicle Routing" (OVR) option from the dialog window. If this step is done before a map is opened, the macro will request for a GIS map to be opened. Upon successful selection of the OVR macro, a tool-box appears in the computer screen with 10 buttons that control the execution of the routing process. This tool-box is shown in Figure 3.1. The general flow of execution is from top to bottom of the tool-box.
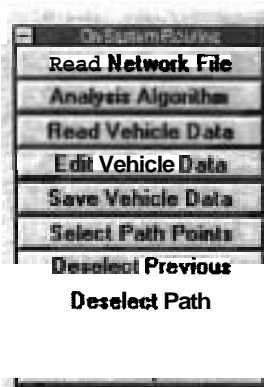
Figure 3.1. OVR Macro Main Tool-Box.

3.4 Reading a Network file and Selecting an Analysis Algorithm

Once a map is selected and the OVR macro has been invoked, a Network file must be selected. This file must have been previously created and contains the description of the working network associated with the map. By clicking on "Read Network File", a dialog box appears prompting the user to select an existing road network file. A message is displayed at the bottom of the screen indicating that the file is being read. When finished, a message appears on the screen. Click "OK" to continue.

Next the analysis algorithm must be selected. Clicking on the "Analysis Algorithm" button allows displays a new dialog box. Two choices are available: "Shortest path" and the "Maximum capacity route". The shortest path algorithm finds the shortest path between any number of points (using the Select Path Points button) that satisfies the vehicle's vertical and horizontal constraints, as well as the vehicle's weight. The "Maximum Capacity route" algorithm is not yet available but will be later implemented. Figure **3.2** illustrates the dialog boxes for reading the network file and selecting the algorithm.
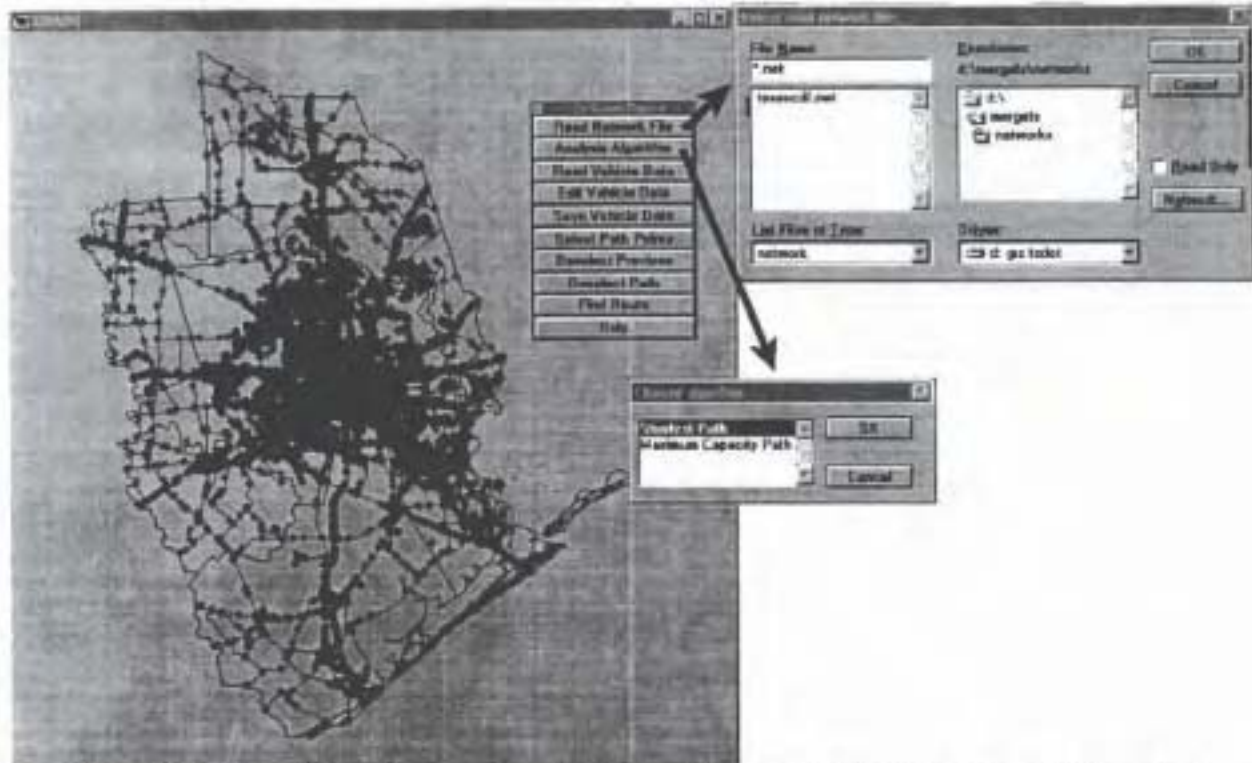
Figure 3.2 Dialog Boxes for Reading the Network File and Selecting Analysis Algorithm.

3.5 Vehicle Information

The next step consists of entering or reading into the program the vehicle characteristics. Two options are available: (1) read the vehicle information from an existing file, or (2) enter a new vehicle description or modify an existing file. The first option is accomplished by clicking on the "Read Vehicle Data" button. A dialog box appears prompting the user to select an existing text file with the vehicle information. This existing files must have been created by pressing the "Save Vehicle Data" button. To select a file, choose the drive and subdirectory where the vehicle file is located. Then, click "OK" or double-click on the file name. When the program has finished reading the file, a message appears on the screen saying: "Finished reading vehicle information". Click "OK" to continue.

The second option permits to enter a new vehicle description or to modify an existing description. This is done by pressing the "Edit Vehicle Data" button. A dialog box appears prompting the user for the "Initial data" pertaining to the vehicle description. This initial data include vehicle model, type, nominal capacity, height, width, total number of axles and an impact factor associated to the speed at which the vehicle is expected to cross the bridges. The vehicle's total number of axles includes the tractor's axles as well as the trailer's. The parameters in these boxes are initially blank when the second option is selected. The impact factor should be selected between three options 0%, 10%, or 30%. If a vehicle is assigned an escort, or if the

velocity is limited, then an impact factor of 10% is recommended. If the vehicle has no monitoring or velocity restrictions, an impact factor of 30% is suggested. The default impact factor value is 10%. After entering this information, click "OK" to continue. The program is now ready for a description of the vehicles' axle configuration and prompts the user to update the axle individual information. If "Yes" is selected, then a new set of dialog boxes appears on the screen to provide the individual axle description. The axle information consists of distance from the previous axle (zero for the first axle), total axle weight, number of tires in the axle, axle gage, and tire width (all tires per axle are assumed to have the same width). The axle gage is the distance measured between the centers of gravity of the two tire groups.

If a new vehicle description has been entered or an existing description modified, the information can be saved by clicking on the "Save Vehicle Data" button.

Figure 3.3 illustrates a superheavy vehicle for which an overload permit was requested at the MCD. The vehicle's total weight is 648 tons. Figure 3.4 illustrates the dialog boxes related to the "Read Vehicle Data" and the "Edit Vehicle Data" buttons. The values in the input boxes pertain to the vehicle in Figure 3.3.
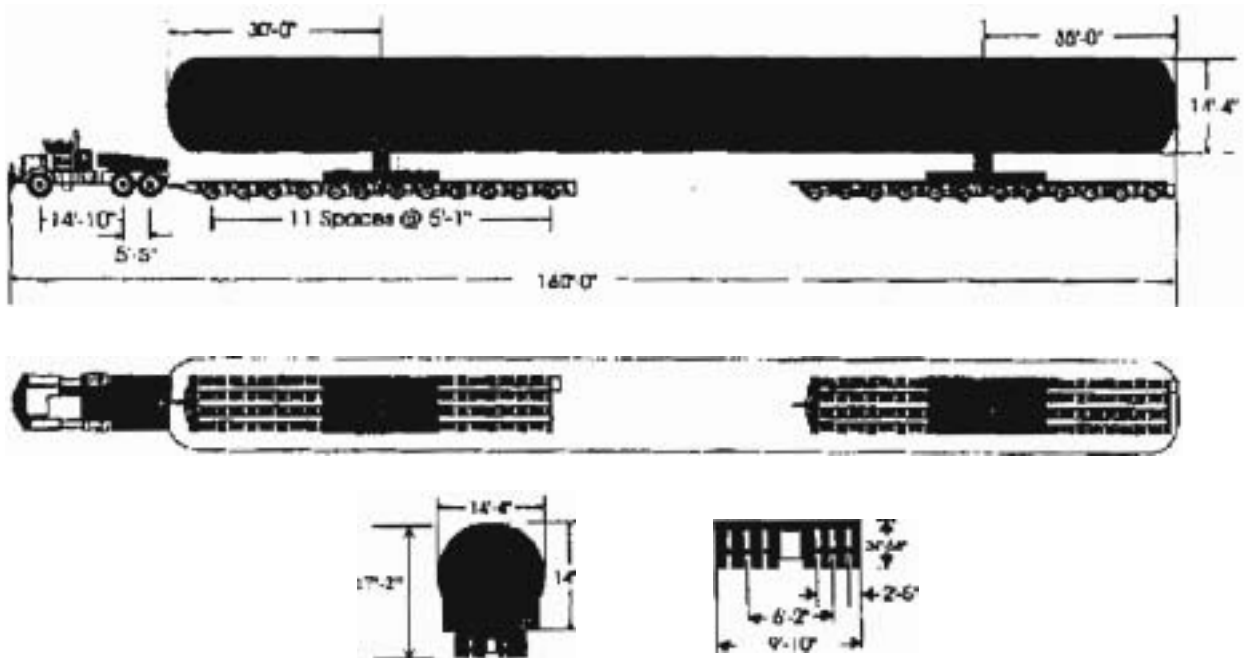
Figure **3.3** A Superheavy Vehicle, 648-ton Capacity, 27 Axles.
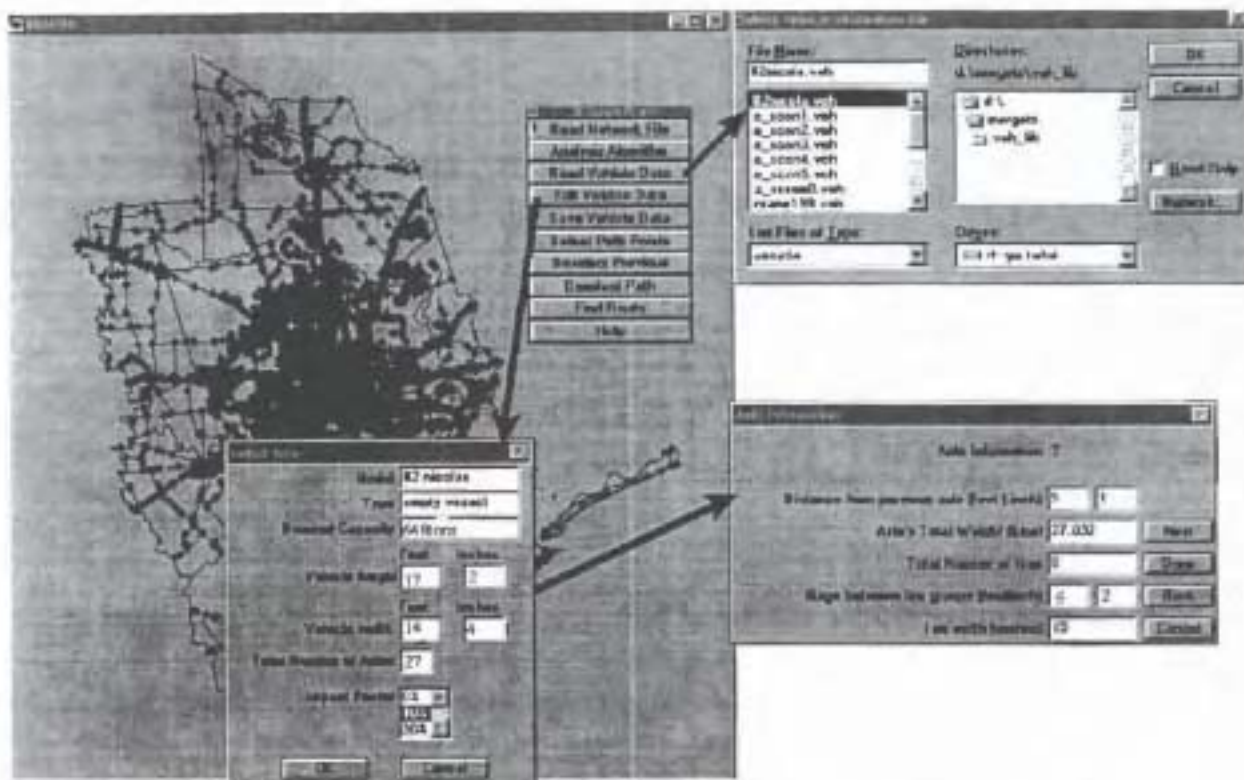
Figure 3.4 Illustration of Dialog Boxes Related to Vehicle Description.

3.6 Selection of Path Points

The route selection for the OVR macro to determine starts by the definition of the origin and destination and optional intermediate points. Clicking on the "Select Path Points" button of the main toolbox does this. When this button is pressed, the Endpoints layer is automatically activated and the user can select an unlimited number of "end" points to define the desired route. When selecting an endpoint, the user needs to use the zoom capabilities of software in congested areas. The first point selected is the origin; the last point is the destination. Any other point is considered as intermediate points (stopping points). If a mistake is made in selecting a point, the "Deselect Previous" button can be pressed to delete the previous entry. If mistakes are made in selecting various points, the user can delete the entire set of points by pressing "Deselect Path". Figure 3.5 illustrates the selection of path points.
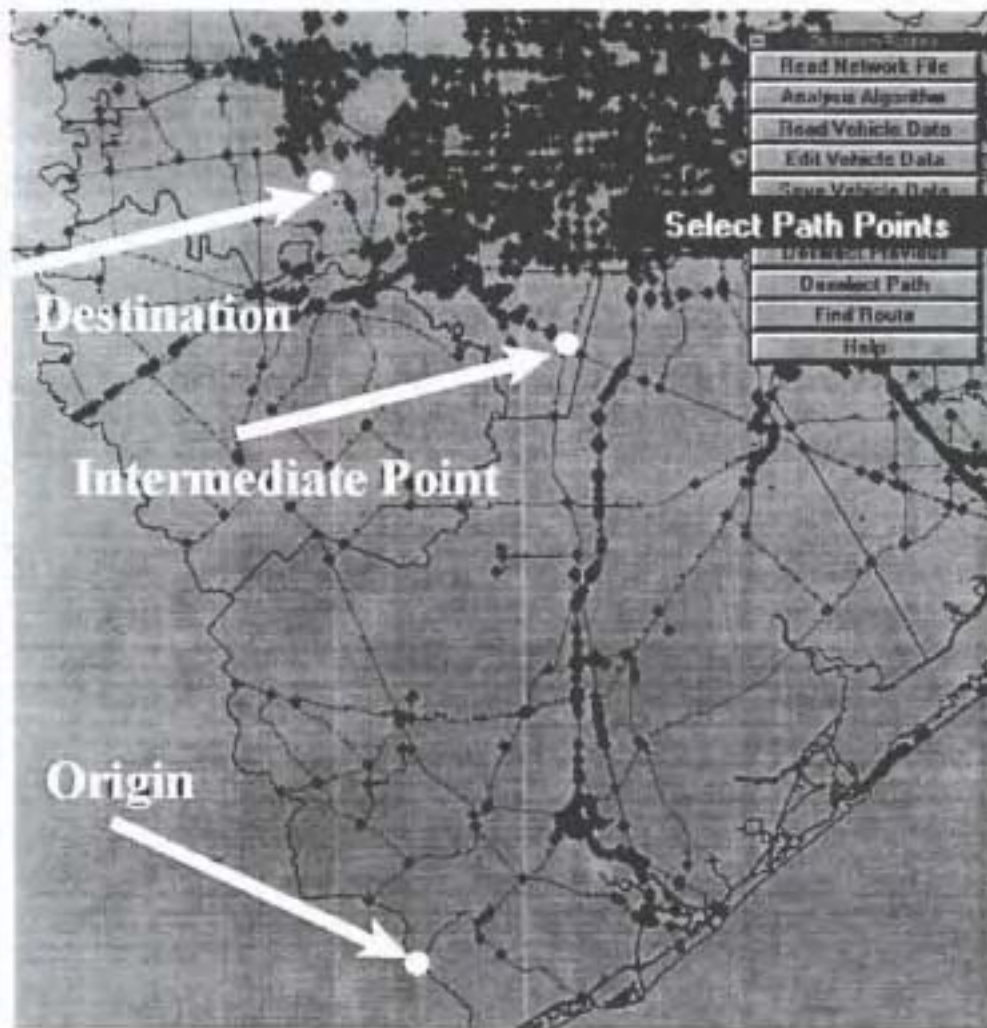
Figure 3.5 Illustration of Selection of Path Points to Define Routes.

3.7 Determination of Route

After selecting the path points, the user needs to press the "Find Route" button to invoke the OVR routing algorithms. This displays a dialog box prompting for the selection of an existing output file or the creation of a new output file. This file is the routing report summarizing the input, the route description, the feasible route found, and the bridges that need to be avoided due to clearances and weight restrictions. Immediately after the output file is selected or entered, the program starts running.

Several "status bars" may appear on the screen reporting two stage indicators, the possible route number being tested, and the restrictions being tested on the bridges of the current route. If an underpass bridge is encountered it checks for both vertical and horizontal restrictions. If a bridge is to be crossed over, horizontal restrictions are checked, in addition to weight capacity. The

status bars indicate the progress of the checks in terms of percentage checked for each possible route found.

In addition to the status bars, some links are highlighted with different colors. This indicates that the links have been disabled. Links disabled by vertical constraints are highlighted in pink. Those disabled by horizontal constraints are highlighted in violet. Links disabled by weight constraints are highlighted in red. Links disabled due to missing information in the BRINSAP database are highlighted in yellow.

When the routing macro finishes the route searching process, two possible outcomes can be expected: (1) A route was found that meets the clearance and weight criteria, or (2) a route was NOT found for the specified vehicle and routing points. In either case, a final report is generated. When a route is found, it is displayed in the computer screen. Figure 3.6 shows a route that was determined for a vehicle using the path points shown in Figure 3.5.
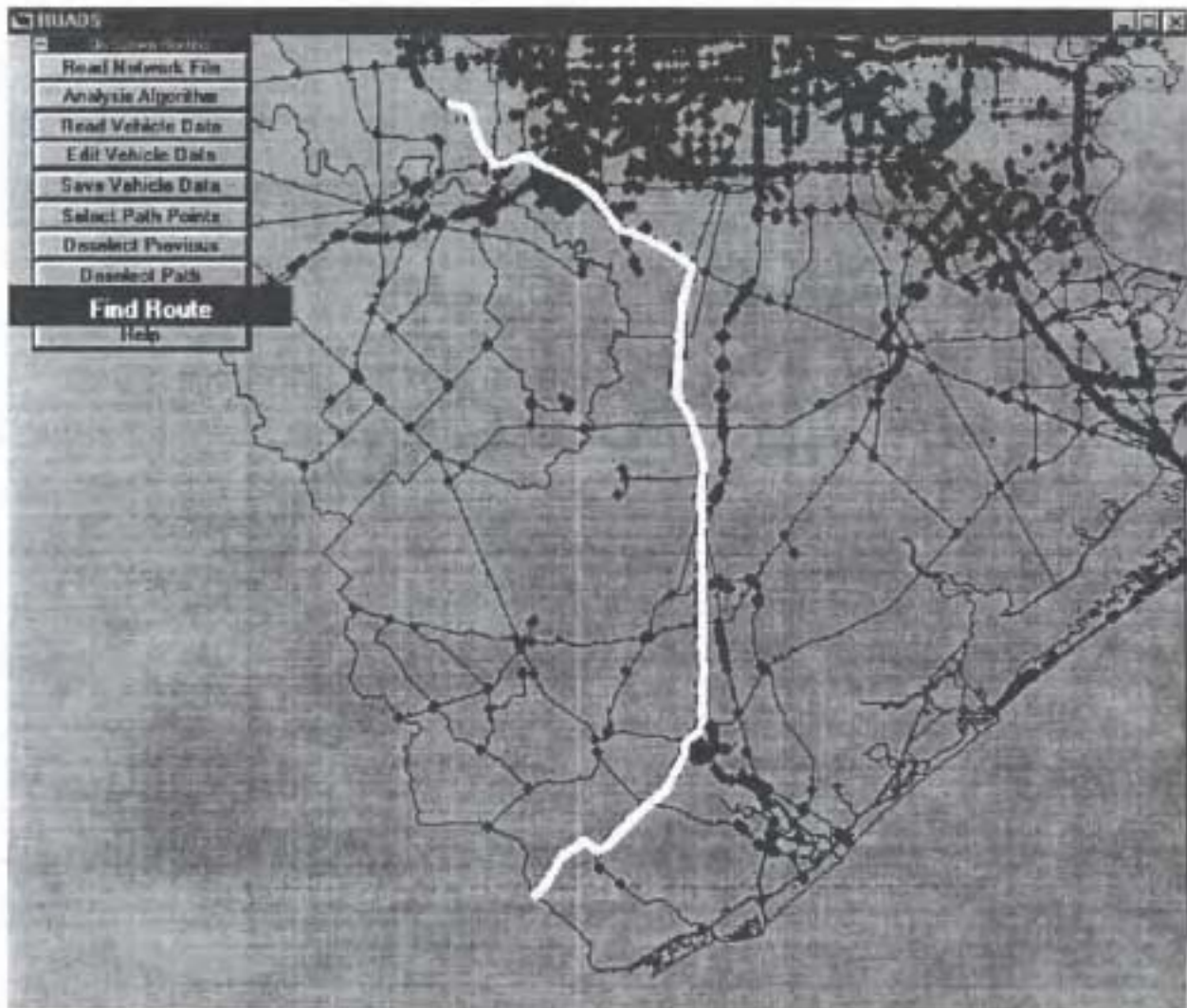
Figure 3.6 Feasible Route Found for an Overweight Vehicle.

A typical report is illustrated in Figure **3.7.** This report is automatically launched using NOTEPAD so it can be viewed. First a "Vehicle description" section is found at the beginning of the report. In addition the computed center of gravity of the total vehicle load is also included. Then follows the selected route input consisting of the points selected on the map. In addition, the program generates a verbal description of the input points.

Next, the actual route description (if found) is reported by TransCAD with headings, highway ID's, mileage, and the cumulative mileage. If a route was not found, the possible reasons are reported in the following sections. Whether a route was found or not, the report includes a list of bridges that might have been avoided due to the different restrictions encountered during the routing search. The total number of routes tested by the OVR macro, before a final result was reached, is also reported.

The following sections can be found if some bridges were avoided due to the several constraints encountered. Each section is classified according to (a) Bridges avoided due to vertical clearance constraints, (b) Bridges avoided due to horizontal width constraints, (c) Bridges avoided due to weight capacity constraints, and (d) Bridges avoided due to missing information in BRINSAP database. For all the classifications, the report includes the bridge structure number according to BRINSAP, the unique numerical link ID where bridge is located (for TransCAD), Highway ID and heading (if available), and the specifics on the pertaining constraints. For example, for (a) above, the report includes the limiting vertical under-clearance in BRINSAP; for (c) information regarding axle groups, allowable vs. Actual axle group weights, axle group IDs, and bridge load formulae under which the axle groups failed, are listed. For item (d) the report list the missing BRINSAP information (i.e: operating rating, total number of spans, total structure length, maximum span length, vertical under-clearance, or total horizontal clearance). Finally, the report lists the elapsed time that the computer took in determining a route. The report can be closed without having to save it.

Overweight/Oversize Vehicle Routing Report

■■■ Uehicle Description ■■■
Model   : 82 nicolas
Type   : empty vessel
Nominal Capacity: 364998
Heigth (ft | in): 16 | 11
Width (ft | in): 12 | 0
Number of Axles : 15
Impact   : 10 %

AxlID	Dist.prev.axl(ft)	Weight/axl(kips)	No.Tires	Gage(ft)	Tire_Width(in)
01	00.000	000016.000	2	06.000	14
02	14.833	000024.250	4	07.000	14
03	05.417	000024.250	4	07.000	14
04	00.000	000027.032	8	08.333	15
05	05.003	000027.032	8	08.333	15
06	05.003	000027.032	8	08.333	15
07	05.003	000027.032	8	08.333	15
08	05.003	000027.032	8	08.333	15
09	05.003	000027.032	8	08.333	15
10	07.147	000023.034	8	08.333	15
11	05.003	000023.034	8	08.333	15
12	05.003	000023.034	8	08.333	15
13	05.003	000023.034	8	08.333	15
14	05.003	000023.034	8	08.333	15
15	05.003	000023.034	8	08.333	15

Vehicle's center of Gravity from the 1st axle is = 0079.45ft

■■■End of Uehicle Description■■■

***Route Description*—

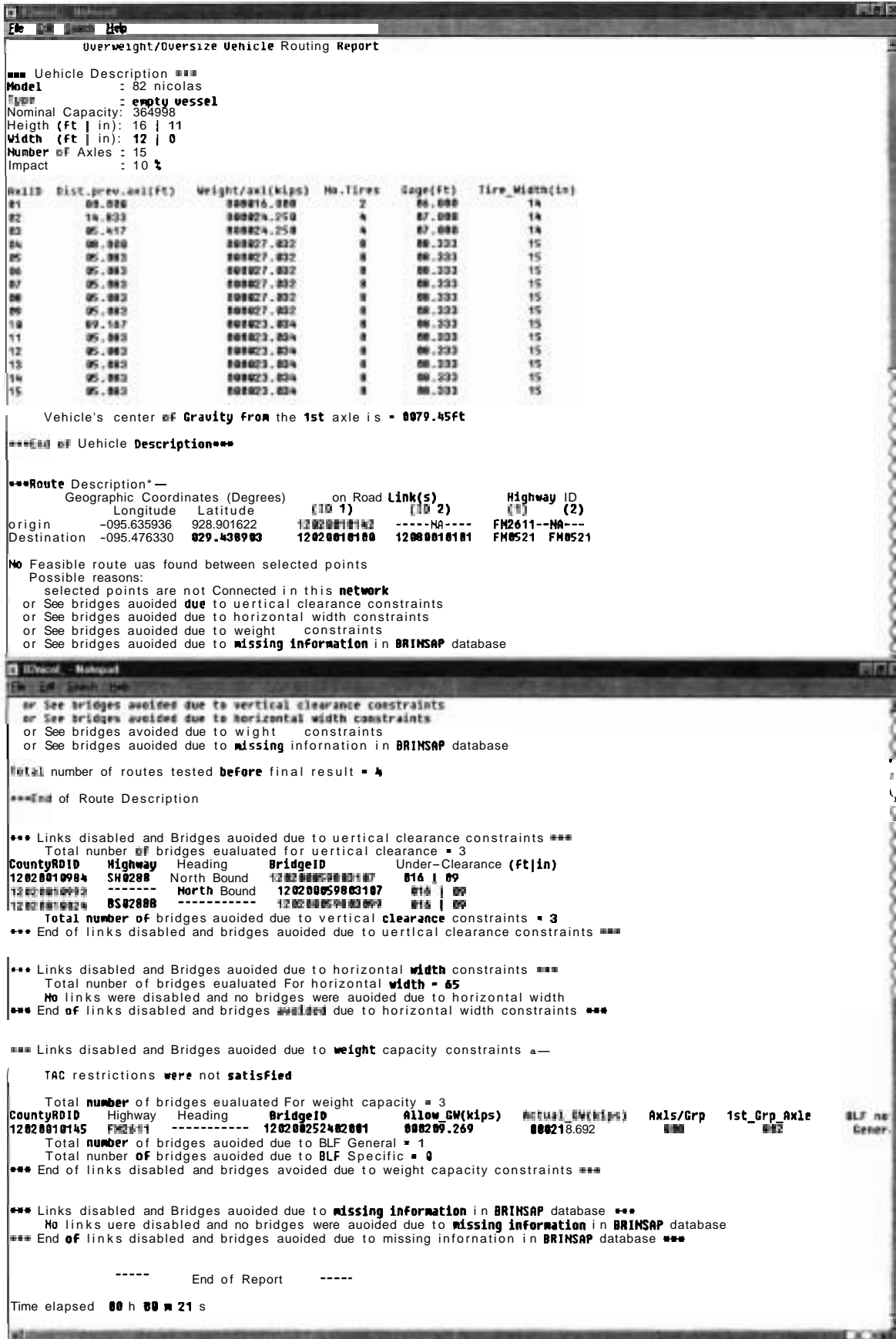|	Geographic Coordinates (Degrees)		on Road Link(s)		Highway ID	
	Longitude	Latitude	(ID 1)	(ID 2)	(1)	(2)
origin	-095.635936	029.901622	12020010102	-----NA----	FM2611--NA---	
Destination	-095.476330	029.438903	12020010100	12020010101	FM0521	FM0521

No Feasible route uas found between selected points
   Possible reasons:
      selected points are not Connected in this network
   or See bridges auoided due to uertical clearance constraints
   or See bridges auoided due to horizontal width constraints
   or See bridges auoided due to weight   constraints
   or See bridges auoided due to missing information in BRINSAP database

Total number of routes tested before final result = 4

***End of Route Description

*** Links disabled and Bridges auoided due to uertical clearance constraints ***
      Total nunber of bridges eualuated for uertical clearance = 3

CountyRDID	Highway	Heading	BridgeID	Under-Clearance (ft|in)
12020010904	SH0288	North Bound	12020059003107	016	09
12020010903	-------	North Bound	12020059003107	016	09
12020010924	BS0288B	----------	12020059003109	016	09

      Total number of bridges auoided due to vertical clearance constraints = 3
*** End of links disabled and bridges auoided due to uertIcal clearance constraints ***

*** Links disabled and Bridges auoided due to horizontal width constraints ***
      Total nunber of bridges eualuated For horizontal width = 65
      No links were disabled and no bridges were auoided due to horizontal width
*** End of links disabled and bridges auoided due to horizontal width constraints ***

■■■ Links disabled and Bridges auoided due to weight capacity constraints ■—

      TAC restrictions were not satisfied

      Total number of bridges eualuated For weight capacity = 3

CountyRDID	Highway	Heading	BridgeID	Allow_GW(kips)	Actual_GW(kips)	Axls/Grp	1st_Grp_Axle	BLF ne
12020010145	FM2611	----------	12020252402001	000209.269	000218.692	000	002	Gener-

      Total number of bridges auoided due to BLF General = 1
      Total nunber of bridges auoided due to BLF Specific = 0
*** End of links disabled and bridges avoided due to weight capacity constraints ***

*** Links disabled and Bridges auoided due to missing information in BRINSAP database ***
      No links uere disabled and no bridges were auoided due to missing information in BRINSAP database
*** End of links disabled and bridges auoided due to missing infornation in BRINSAP database ***

      -----   End of Report   -----

Time elapsed 00 h 00 m 21 s

Figure 3.7 Typical Routing Report.

CHAPTER 4

ROUTING MODIFICATIONS

4.1 Summary

This chapter is devoted to the description of three proposed modifications to enhance the routing software. These are: (1) avoidance of U-turns, **(2)** improvement of the computational procedure to check bridges on a given route, and **(3)** sorting bridges on the basis of rating and the longest span length fields in the BRINSAP database while evaluating.

4.2 Avoidance of U-turns

The current version of the software does not consider restriction on U-turns due to the limiting turning radii of most **oversize/overweight** vehicles. More realistic paths can be found by incorporating TransCAD's "NO U-turn" feature. This enhancement also increases the efficiency of the optimal path finding procedure. This is because the number of feasible paths that can be generated under the "NO U-turn" restriction is significantly reduced.

TransCAD has the capability to automatically apply the no U-turn restriction to an entire network. Because of this capability the routing macro does not need to check each route for improper U-turns. To apply the no U-turn restriction to an entire network, the following steps are used:

    a. Choose *Networks/Path-Setting* to display the *Network Setting* dialog box.
    b. Select *Turn Penalties* from the *Options Fields.*
    c. Select *Default* from the *Turn Penalties Fields.*
    d. Select *U-Turn* from the *Movement Fields.*
    e. Click *OK* to display the *Save Network As* dialog box.
    f. Select the directory *c:\tcw* and enter *ovrUturn.net* as the file name. Click OK.

TransCAD creates a network file with the selected set of links and displays the network filename on the status bar at the right bottom of the screen. In order to assess the effect of the no U-turn on the computational requirements of the routing macro, several runs were designed to yield results with and without the U-turn. These computational comparisons showed that significantly less computer time is needed to either find a path or conclude that there is no optimal feasible path.

4.3 Improvement of the Computational Procedure to Check Bridges on a Given Route

During the iterative process for evaluating the bridges of an unconstrained shortest path, a flag field in the BRINSAP GIS layer is temporarily created. This field is used to record those bridges that have already been evaluated for clearance, width and weight restrictions.

This avoids repeating evaluations of bridges already checked. This modification dramatically improves the efficiency of the routing procedure because a bridge that is feasible for one path will be feasible for another path for the same vehicle.

When the modified routing procedure is executed, the BRINSAP layer is accessed and a new field called *flag* is created. This field is an integer with a width equal to one. Whenever a bridge is evaluated, the *flag* field is checked first. If the value is "null," then the bridge has not been evaluated yet, and therefore, the bridge adequacy is evaluated. If the bridge is found feasible, an integer value of 1 is assigned to this field; otherwise, no action is taken since the link is disabled and will not be further considered. Upon completion of the routing procedure, the *flag* field is removed from the BRINSAP layer. A significant reduction in computational time is expected from the incorporation of this modification.

4.4 Sorting Bridges While Evaluating

In the present running version of the program, the shortest path is first found and then the bridges are individually evaluated in the order that are to be crossed. If a bridge is found inadequate due to weight restrictions, then the program stops checking the remaining bridge on the tentative shortest path. The link is then disabled and a new shortest path is found. For long paths with many bridges, it may be advantageous to quickly identify the critical bridges and start the evaluation process by evaluating first the bridges that are believed to be unfeasible. This process would require sorting of the bridges along the route according to some criteria.

Here, two criteria are tested: (1) sorting bridges in descending order according to the length of the longest span. And (2) sorting bridges is ascending order according to the operating rating.

Since both pieces of information are readily available through BRINSAP, these sorting schemes were experimented with. This process was done using built-in functions that locate maximum and minimum values of an array. For the first criterion, the process used is as follows: (a) Identify all bridge structure numbers along the unconstrained shortest path. (b) Retrieve the values of the length of the longest span from BRINSAP and store them in an array. (c) Identify the bridge with the longest span through use of the "maximum" built-in function, (d) And evaluate the adequacy of this bridge. If the bridge is adequate, then bridge with the next longest span is evaluated and the computation continue until a bridge is found inadequate or all the bridges are evaluated. If a bridge is found inadequate, the link is disabled and a new shortest path is found.

For the second criteria, a similar process is used but in terms of the operating rating. In step (b), the process retrieves the operating rating from BRINSAP. In step (c), the "minimum" built-in function is used to find the bridge with the lowest rating. The remaining steps are the same.

Based on the computer runs, both of the sorting methods failed to demonstrate any distinguishable reduction in computational time. In fact, in some instances, it increased the computational time. As a result, it was decided not to implement this modification.

4.5 Proposed Future Enhancements

The purpose of this section is to emphasize the need to make the routing of overweight/oversized vehicles more realistic for the permit office to issue permits in an effective and efficient manner. In particular, in addition to finding shortest paths, we recommend three enhancements:

(1)   Determine routes having the largest possible safety margin.

(2)   Incorporate a turn-penalty procedure in the routing of oversized vehicles to avoid undesirable or impossible turns.

(3)   Include a user-friendly procedure to temporarily disable portions of the network that might not be open to traffic in a temporary situation.

4.5.1 Routes With Maximal Safety Margin

Here the safety margin of a route is defined as the difference between a bridge load carrying capacity and the load of the truck. Because of the high number of bridges within the State of Texas, determination of a maximal capacity path involves the iterative finding of a large sequence of shortest paths with increasing capacities.

In essence, the procedure can be outlined as follows. Once a feasible shortest path is found, the road sections containing all bridges with critical capacity (minimal capacity) are disabled. Next, another feasible shortest path can be found from the remaining network. This procedure can be repeated until no more feasible routes are found due to the capacities of the remaining road sections. The last available route is both feasible and has the largest safety margin for the given vehicle.

4.5.2 Routes without Unacceptable Turns

Given a typically a road intersection, it is possible to define a "penalty" value for each turning maneuver that can be performed at intersections. This is an important aspect in the routing of oversize/overweight vehicles because some of these vehicles have limiting turning radii. We recommend a macro that can automatically assign turn penalties to the turning maneuvers at intersections according to the vehicle's information and that can identify paths with acceptable turns.

4.5.3 Procedures to Disable Portions of the Network

Because of traffic congestion or construction requirements, or other limitations, several road sections may not be available to be part of the shortest route for an overweight or oversized vehicle. In this case, the user may want to temporarily disable restricted links of the network. A macro can be programmed to update the network and use this updated network to find a path. However, the problem is that the actual road conditions are so dynamic that making such a system fail-proof and compiling information from TxDOT's 25 Districts is a big challenge. This challenge probably involves technology for managing information.

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CHAPTER 5

BRIDGE MANAGEMENT APPLICATIONS

5.1 Summary

The development of the overweight/oversize routing software has provided the capabilities of graphical access of the BRINSAP records and displaying bridge location as functions of BRINSAP records that satisfy a desired criterion. These two capabilities have great value for bridge management applications.

5.2 Graphical Access to BRINSAP Records

One of the benefits of the GIS system developed is that the BRINSAP information is readily available. In any GIS map, when the BRINSAP layer is activated, the user can inquire about the information of any particular bridge by clicking on the point representing the bridge location. A window showing a table of the BRINSAP fields along with the corresponding values is then displayed. Any particular field can be searched by scrolling. Figure 5.1 illustrates this capability. The figure corresponds to a display of all load critical bridges in the State of Texas. The highway network was deactivated for clarity purposes.
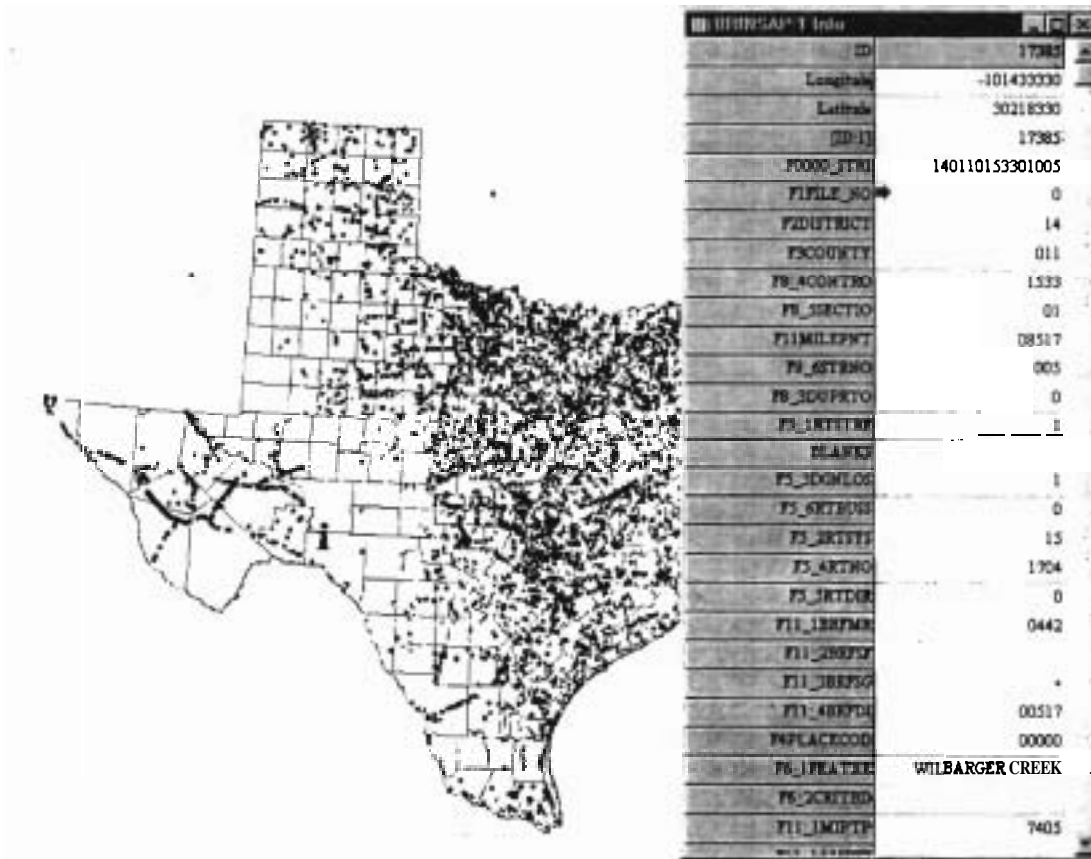

Figure 5.1 Access of BRINSAP Records through the GIS System.

5.3 Displaying Bridges as Functions of BRINSAP Records

The BRINSAP office of TxDOT's Design Division usually receives several requests from the District offices or others to produce maps indicating the location of bridges that meet certain criteria. Usually the Districts want to know the bridges that are posted, designed for H15 vehicles, etc. The system developed in this project has the capabilities of producing these maps. The software is simply instructed to display the bridges that meet certain criteria according to the values stored in the BRINSAP records.

To illustrate this process, Figure 5.2 is made reference. This figure shows the Texas On-system bridges that are load posted. This map was produced using the following procedure:
(1) The layer showing the political boundaries of Texas was loaded.
(2) The BRINSAP layer was overlayed.
(3) The interstate highway roads from USGS files were also overlaid.
(4) The "Select by Query" function of the Software was used to identify all bridges that are posted. The query specifically requested the bridges that have a value of either K, P or R in Field 41 of BRINSAP (Structure Open, Posted or Closed to Traffic).
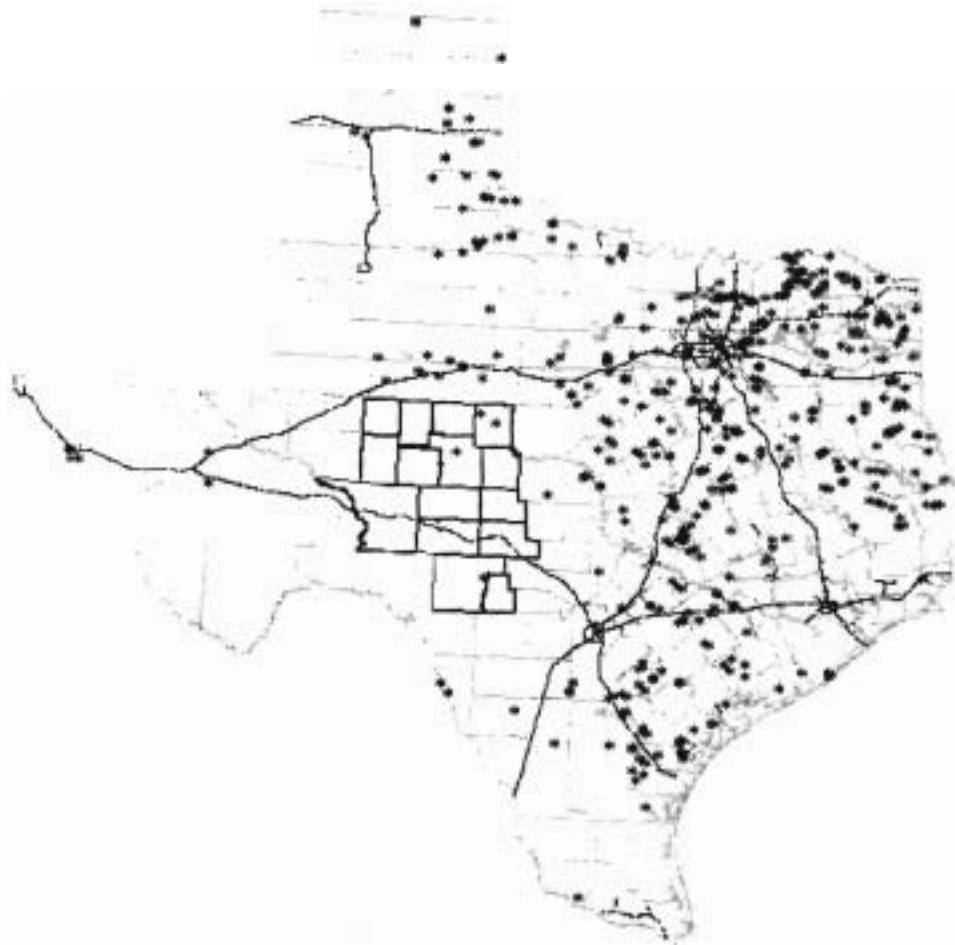

Figure 5.2 Load-Posted Bridges of Texas.

The highlighted counties in Figure 5.2 correspond to the political boundaries corresponding to TxDOT's San Angelo District. Notice that within this District there are only **3** bridges that are load-posted. Recently, the District office of San Angelo recommended load-posting about 349 bridges within the district. Before, their recommendation were followed, the Design Division requested a map of where these bridges are located. Figure 5.3 shows the bridges of San Angelo District that were recommended for posting. The figure was produced by requesting the software to display the bridges according to a list of structure numbers and geographic coordinates provided by TxDOT.

Figure 5.2 Bridges Recommended for Load-Posting in **San** Angelo District.

Two additional maps that **TxDOT** requested were to display the location of fracture critical bridges and underwater bridges in the State of Texas. These maps were produced in a similar manner to the previous ones in Figures 5.1 and 5.2. Figure 5.3 displays the location of the underwater bridges. Figure 5.4 displays the location of the fracture critical bridges.

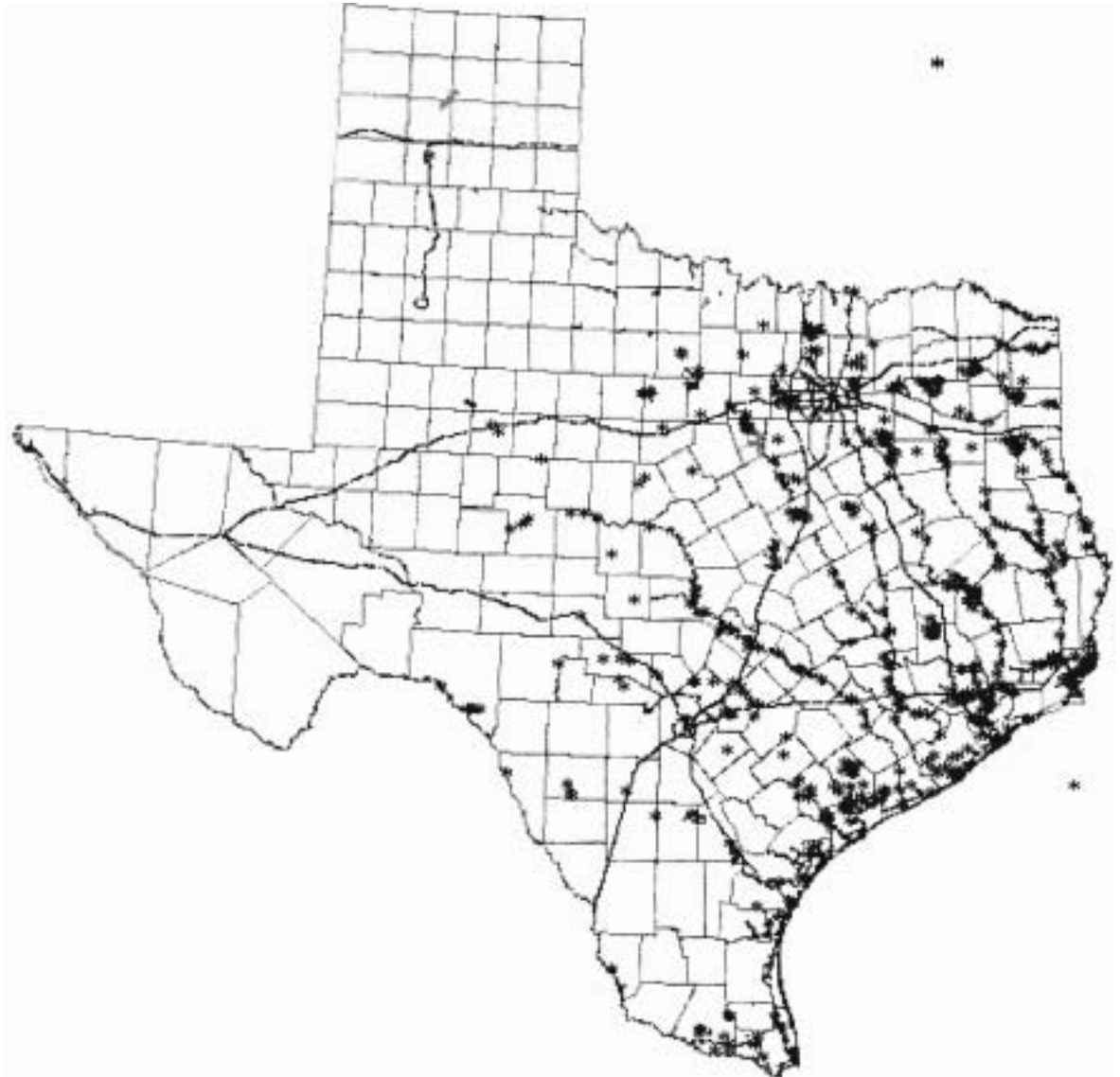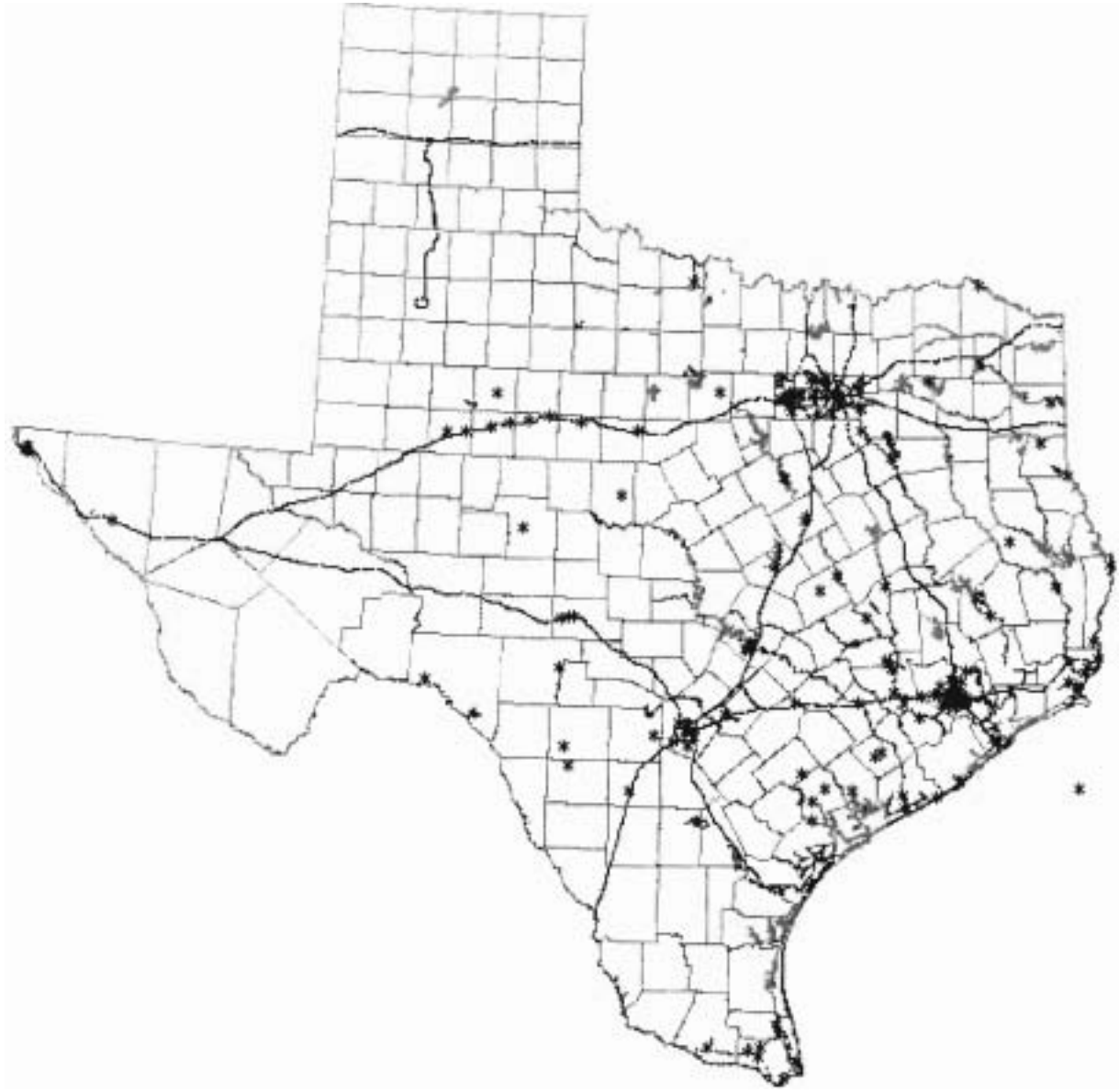**Figure 5.3 Texas Underwater Bridges.**

Figure 5.4 Texas Fracture-Critical Bridges.

CHAPTER 6

SUMMARY

6.1 Summary

The objective of this project was to develop an automatic procedure for evaluating the adequacy of bridges along routes for overweight/oversize vehicles. The procedure developed uses a network representation of the On-system roads to identify inadequate bridges in the vehicle's route. The network model is included within a Geographic Information System operating in the PC environment. The model was based on the On-system roadways and simulates the travel of vehicles within the On-system highways only. The system automatically finds a shortest path between an origin and a destination disabling segments with inadequate bridges due to capacity or clearances for a given overload/oversize vehicle. The system, however, only responds to the information that is included within the GIS and does not consider other routing factors such as construction activities, roadway obstructions and others.

The overweight vehicle is first analyzed according to the Texas Administrative Code requirements. If the vehicle fails to meet these requirements, then the determination of a route is performed evaluating the bridges using the Bridge Load Formulae and the rating and description parameters included in BRINSAP. Since the system links to BRINSAP through the bridge identification, the future incorporation of PONTIS will allow a more accurate bridge evaluation without the need of empirical formulae. The efforts of this project focused on implementing an operational system that addresses the routing process of superheavy loads.

In addition to routing, the system has important uses in bridge management. The system is capable of displaying bridge location according to the information in the BRINSAP database. This has provided the TxDOT Design Division with the capability of quickly producing bridge location maps according to desired attributes.

This report includes:
(1) A summary of the work accomplished under the different tasks of the project.
(2) A description of the operation of the GIS system to route overweight/oversize vehicles.
(3) A description of three proposed modifications to enhance the routing software to consider or improve the avoidance of U-turns, the computational procedure to evaluate bridges, and sorting of bridges on the basis of rating and the longest span length. And
(4) Illustration of bridge management applications of the system.

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