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GIS-BASED OVERSIZE/OVERWEIGHT VEHICLE ROUTING SYSTEM

FINAL REPORT

by

Teresa M. Adams, Principal Investigator
Professor, Civil and Environmental Engineering
2208 Engineering Hall
1415 Engineering Drive
Madison, WI 53706
adams@engr.wisc.edu
608/262-5318

Suphawut Malaikrisanachalee,
Carola Blazquez,
and
Alan P. Vonderohe
Professor, Civil and Environmental Engineering

of the

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING
UNIVERSITY OF WISCONSIN-MADISON

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16. Abstract

This project consisted of the design and development of an automated oversize/overweight permit processing application to overcome current paper and labor-intensive processes within the Wisconsin Department of Transportation. This application links with various systems for retrieving the customer and vehicle information, evaluating temporal and physical restrictions, performing bridge structural analysis, and route generation. The main program of the application links two programming languages (Java and Visual Basic) that interact with heterogeneous databases for evaluating restrictions and incorporating customer information, an external executable program for verifying bridges on a route, and a GIS tool for route generation and display. The resulting application consists of functions and activities seamlessly combined together to generate route and escort instructions, trip conditions, restricted bridges, and maps that are appended to the permit information available for the motor carrier's use during the trip. The application will improve customer service through faster turnaround time on permit applications causing cost reductions for motor carriers. The automation of permit application will minimize human intervention and alleviate the workload of the transportation agency personnel. Lastly, the application will increase public safety by delivering optimized routes with enhanced accuracy as various datasets are integrated to verify restrictions on the routes.

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EXECUTIVE SUMMARY

Project Summary

This project tested Wisconsin Department of Transportation's (DOT) link/site topological network and linear location reference system as the basis for a dynamic network analysis system capable of automated, real time evaluation of a proposed route and generation of a best route. Accordingly, this research built and tested a routing system (herein referred to as the OS/OW Vehicle Routing System) that evaluates vehicle size and weight against the Wisconsin DOT's State Trunk Network (STN) Inventory containing roadway and bridge characteristics, construction-related restrictions, and other sample restriction data.

Background

This particular research effort was motivated by a desire within the Wisconsin DOT's Division of Transportation Infrastructure Development (DTID) Bridge Section to reduce the burden of managing bridge-related route restrictions in the current "Route-Check" program. The route-check program relies on bridge-to-bridge sequences of bridge locations referenced to routes. The method requires redundant data entry for routes on/under bridges and for concurrent routes. The research explored the possibility of transforming bridge-to-bridge sequence references to link-offset locations and the impacts on business processes for increasing currency of the LCM and for managing bridge data in the STN.

The DTID successfully sought funding for this research to study alternatives to improve coding of bridges and improve the OS/OW (oversize/overweight) routing function related to bridges. At the same time, concerns about longer permit turnaround time and increasing complexity of permit evaluation prompted the Division of Motor Vehicles (DMV) to seek funding for an automated routing and processing system in the 1999-2001 State Biennial Budget. In departmental discussion, it became clear that automating the OS/OW permitting process would be a complex effort requiring extensive interdivisional coordination. A Memorandum of Understanding between the Bureau of Automation Services (BAS) and DMW called for a scoping team to "do a thorough technical assessment of what needs to be done to achieve the automated permitting system described in the *OS/OW Routing System Plan: Phases One-Four* paper dated 11/23/98. The routing system design for this project follows the recommendations of the resulting Oversize/Overweight Permit Processing System Scoping Project report dated April 30, 1999.

The University of Wisconsin-Madison conducted the research. Professor Teresa M. Adams was the Principal Investigator and directed the project. The Research Team included Professor Alan P. Vonderohe and graduate students: Carola Blazquez, Suphawut Malaikrisanachalee, and Scott Lueck.

Process

This research designed, built and tested a prototype GIS application for routing OS/OW vehicles in Wisconsin. The design phase was conducted from July 1999 through June 2000. The application development phase was conducted from July 2000 through October 2000. The final demonstration was conducted in November 2001, and project reporting continued until March 2002.

The project focused on two trial corridors:

1. Milwaukee County Interchange - E / W corridor because of its richness of detail with STH to STH; STH to local streets; and ramps.
2. District 5 STH 35 - Prairie Du Chien to Hudson.

The Bridge Log and STN inventory of bridge locations for these corridors were compared to evaluate the fit-for-use of the STN bridge link-offsets for identifying bridges on routes and to evaluate whether the current bridge-to-bridge coding logic in the Bridge Log can be automatically translated to equivalent STN link-offsets. The Research Team developed the Bridge Evaluation Program (BEP) tool that automatically detects discrepancies between the Bridge Log and the State Trunk Network (STN) inventory for bridge location. The BEP tool was used on bridges in both trial corridors.

Development of the data model and algorithms for OS/OW routing required numerous meetings with WisDOT personnel so that the Research Team could better understand the available data and its use in the route checking process. Conceptual and physical data models were developed to manage temporal and physical route restrictions as needed for spring-thaw, construction, bridges, non-standard highways, special events and escorts. The resulting OS/OW routing database model is compatible with the WisDOT agency sources of restriction data to facilitate the programming of bridging interfaces.

Alternative algorithms for generating and checking route restrictions were evaluated. The algorithms codified the high-level procedures and logic for checking restrictions. The actual path finding part of the algorithms depend upon built–in GIS tools operating on the WisDOT's link/site topological network as the data source for path finding between origin and destination. The routing engine can generate the shortest path between origin and destination or test a predefined route submitted by a permit applicant. The routing engine includes seamless linkage to the WisDOT bridge structural analysis program.

The automated routing engine was implemented using two programming languages (Visual Basic and Java) that interact with a GIS tool (ArcInfo) and a database management system (Oracle) to produce an optimal route that best accommodates the vehicle. The resulting application generates route and escort instructions, trip conditions, restricted bridges, and an illustrative map with permit information for the motor carrier's use during the trip. The routing engine is link-able with OPUS/OOPPS. WisDOT provided the topological and the cartographic network as ArcInfo coverages. The cartographic network at 1:100,000 scale was used to prepare examples of OS/OW permit maps with instructions for the motor carrier.

Findings and Conclusions

The primary contributions of this project are the designed and programmed data model and algorithms for WisDOT's OS/OW vehicle routing procedure and the tools for inferring linearly referenced locations of bridges on the STN.

WisDOT's link/site topological network and linear location reference system can be used as the basis for automated near real-time generation and evaluation of routes. The link-offset referencing system supports the integration and management of roadway characteristics and routing restrictions and provides the topological model that is essential for generating routes. It should be noted that this project did not involve coding algorithms for path finding. Rather the project used built-in vendor tools for generating routes. This project concludes that WisDOT topologic roadway network is an extremely valuable raw data source for OS/OW routing.

The STN inventory of bridge link-offsets locations is not fit-for-use to reliably identify bridges on permit routes. While the bridge location references in the current Bridge Log are reliable, the bridge-to-bridge sequences cannot be automatically translated to equivalent STN link-offsets.

Furthermore, the bridge-to-bridge sequences cannot be automatically translated to any other linear location referencing method. To assist with the transformation, the Research Team built a tool (call BEP) to traverse the link/site model looking for bridge-to-bridge sequences so that link-offset locations of bridges can be inferred (not computed). The tool also identifies inconsistencies between the Bridge Log and STN Inventory.

Recommendations for Further Action

Implementation of the OS/OW Vehicle Routing System described in this report will require the development of additional user and software interfaces. Software interfaces are needed to connect the OS/OW Vehicle Routing System to OPUS/OOPPS. This will require the development of a method for communicating origin/destination or user defined routes. Database bridging programs are needed to automatically update the restriction database from WisDOT data sources, such as construction projects and pavement ratings. Finally, user interfaces are needed for entering and managing restrictions that are not derived from existing databases such as detours and spring thaw.

Several recommendations are more general in that they are applicable for the implementation of this or any other system for OS/OW routing. These include the following:

1. WisDOT will need to allocate resources for translating bridge-to-bridge location references in the Bridge Log to locations that are linearly referenced to roadways. The BEP tool will be useful for this task.
2. WisDOT will need to revise business processes so frequent and timely updated LCM and STN datesets are available to the OS/OW vehicle routing syste. Current LCM and STN data are vital for the successful operation of the routing and restriction checking.

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1 INTRODUCTION

1.1 Problem Statement

Current Oversize/Overweight (OS/OW) vehicle permit processing systems are paper-intensive processes that lack linkages with other systems for evaluating permit applications such as for evaluating physical restrictions, checking carrier insurance, structural analysis, and route generation. These current systems are no longer capable of keeping up with customer needs. In Wisconsin, the number of permit applications climbs at 6% yearly and applications are continually more complex, increasing the need for engineering reviews (Wisconsin, 1999). As a result, turnaround time for OS/OW permits has increased, causing costly delays to the motor carriers who apply for the permits.

The current bridge coding method to support route checking is outdated and prone to human error. The current method for permit processing requires human interpretation to distinguish between routes that go over or under bridges and does not support automatic generation of permit routes. There is a desire to improve customer service and reduce response time by using new approaches to automate route generation and streamline the maintenance of associated bridge data.

It is desirable to automate the OS/OW permit process. This project and other papers (e.g. Osegueda et al, 1999) deal with automating the evaluation of restrictions that are related to the physical roadway network. These restrictions include roadway topology, pavement load capacity, bridge capacity, vertical and horizontal clearances, administrative restrictions, construction closures, and local, state and federal restrictions among others. All of these restrictions are locationally referenced.

1.2 Project Objectives

The goal of this research is to design and prototype a GIS-based automated routing application that minimizes updating difficulties of bridge restrictions, while providing improved performance in the permitting process. The project focuses on integrating GIS-based route generation, bridge restrictions, the agency's Oversize Permit Unit System (OPUS)/OOPPS, and bridge structural analysis programs. The project addresses all route restrictions identified in the OOPPS Scoping Study (Wisconsin 1999) but emphasizes the route restrictions currently in the Bridge Log database and route check program. The specific objectives of the research include the following:

(1) Evaluate the fitness-for-use of the WisDOT STN bridge inventory (link-offset) for identifying bridges on routes.

(2) Evaluate whether the current bridge-to-bridge coding logic (Bridge Log) can be transformed to equivalent and reliable STN link-offsets.

(3) Develop a GIS application that generates "best" route (time, distance, interstate); checks restrictions due to bridge clearances, postings, and construction closures; and identifies conditions for permitting.

(4) Develop a GIS application for managing bridge data to support route permitting.

(5) Document the implementation procedure to be used for building the full system.

1.3 Organization of the Report and Intended Audience

This final report was written to be compatible with the OOPPS Scoping Study report (Wisconsin 1999). The report describes accomplishments that satisfy the tasks and requirements in the scoping study report. Section 2 describes the major components of the OS/OW Vehicle Routing System including application algorithms for shortest and pre-defined routes, software platform and architecture, and data models. Section 3 illustrates the prototype application through with a user's manual of the OS/OW Vehicle Routing System. Evaluation of the bridge data on STH 35 and the Marquette Interchange is explained in Section 4. Details of the data requirements for restrictions are presented in Section 5. Finally, Section 6 summarizes the next-steps for fully implementing the GIS-based OS/OW Vehicle Routing System and highlights other implementation issues that may require Wisconsin DOT to revise the business processes that handle restriction data.

The intended audiences of this report are management and technical participants in the implementation of the GIS-based OS./OW Vehicle Routing System, end-users of the system, and agency personnel who will be responsible for entering and maintaining the roadway network and restriction data used to generate and evaluate OS/OW routes.

2 OS/OW VEHICLE ROUTING SYSTEM COMPONENTS

This section describes the major components of the automated GIS-Based OS/OW Vehicle Routing System including restriction checking and route generation algorithms, decision support database as well as the software platform architecture.

2.1 Routing Algorithms

The OS/OW vehicle routing system embodies two routing options: the shortest and pre-defined routes. The shortest route approach provides the optimal solution (in term of travel time or distance) for route selection. The pre-defined route approach, meanwhile, offers the safest route for an OS/OW vehicle based upon the agencies designation.

2.1.1 Shortest Route Approach

Figure 1 illustrates the main program for restriction evaluation and route generation for the shortest route approach. The algorithm was developed assuming a relational database. The control of the algorithm is shown with bold arrows.

Conceptually, the roadway links with restrictions that prohibit an oversize/overweight vehicle from passage during the entire two-week period or some portion (or portions) of the two-week period that the permit is valid are determined. This process can be accomplished non-spatially by a series of queries. The roadway links that are restricted for the vehicle for the entire two weeks are then disabled from the topological network. Meanwhile, the roadway links that are restricted for the vehicle for a portion (or portions) of the two weeks are non-spatially stored in a table and subsequently used to generate the trip provision if the roadway links are part of the permit route.

Once the roadway links that are not accessible for the vehicle are disabled from the topological network, an optimal route is generated spatially from the remaining roadway links. The optimal route generated in this process is the final permit route for an oversize vehicle. However, if the vehicle is overweight, structural analysis of bridges on the route is required. The vehicle is considered overweight, if the overall vehicle weight is greater than 40 tons and if the axle weight of the vehicle (individually and total) for each axle group is greater than the standard criteria employed by Wisconsin DOT. The comprehensive structural analysis is accomplished by a combination of external structural analysis programs and a series of queries to a relational database. If any bridges on the route are not structurally approved, then the roadway links containing the bridges are disabled from the topological network. Then a new optimal route is re-generated from the remaining roadway links and checked against the overweight vehicle.

The route is approved once all bridges on the route are structurally approved. Subsequently, human-readable instructions are generated. The human-readable instructions contain travel directions, trip provisions, escort instructions, instructions for restricted bridges, and a cartographic map of the permit route.

In Figure 1, Modules 1 through 5 find the unqualified and temporally restricted links due to construction restrictions and closures; narrow lane and shoulder widths of non-standard highways; weight restrictions caused by spring-thaw effect; bridge clearance and weight restrictions; and restrictions caused by special events such as football games or parades, respectively. An unqualified link is defined as a roadway link that possesses one or more restrictions that prohibit a vehicle from passage during the entire two weeks that the permit is valid. A temporally restricted link is a roadway link that possesses one or more temporal restrictions that prohibit a vehicle from passage during some portion (or portions) of the two weeks that the permit is valid. The permit route may include temporally restricted links. Trip provisions are accompanying the permit route if temporally restricted links are part of the permit route.

It is noted that Steps 1 through 5 are divided into independent modules that need not be executed in the logical sequence shown in Figure 1. The order shown is the order used for application development.

2.1.2 Pre-Defined Route Approach

Figure 2 illustrates the main program for restriction evaluation and route generation for the pre-defined route approach. Although the pre-defined route approach may not provide the optimal solution in terms of travel distance, it offers an option for a more-convenient route for oversize/overweight vehicles since motor carriers commonly use these routes. In addition, the pre-defined route approach omits the route generation process so it can reduce considerable amount of processing time.

The pre-defined route approach implements nearly the same processes as in the shortest route approach except that the route-generation process is omitted. The pre-defined route approach implements the same Modules 1 through 7 as in the shortest-route approach. Modules 1 through 5 check the entire restrictions due to construction projects, non-standard highways, spring-thaw effect, clearances and posted weights of bridges as well as the local restrictions due to special events. It is more efficient to check the entire restrictions at once rather than checking restrictions on one roadway link, which is a part of the pre-defined route, at a time. If one or more restrictions are found on the pre-defined route, the route fails and the program simply terminates. Otherwise, the program goes through the successive processes as shown in Figure 2.

2.2 Software Platform Architecture

Figure 3 illustrates the software platform architecture of the OS/OW Vehicle Routing System and the envisioned relationship to OPUS/OOPPS application. The main program consists of Visual Basic macros. Visual Basic code, embedded in ArcInfo8 through ArcObjects, performs GIS functions such as generating routes according to user specified origin and destination; acquiring permit information from the Permit Application Interface or through other means; and communicating with Java. Java scripts access and update the OS/OW routing and restriction database managed by Oracle DBMS, and operate the Bridge Structural Analysis Program. Java interfaces directly with the Oracle DBMS. Visual Basic calls ArcInfo8 functions. Visual Basic communicates with Java through text files and executes Java scripts through batch files.

The Research Team considered using ArcSDE (Arc Spatial Database Engine) with the Oracle DBMS. ArcSDE creates a table space in Oracle. ArcSDE data can be accessed as regular Oracle tables, however the object-id column values are managed by ArcSDE and should not be edited through Oracle. Adding or deleting rows in the ArcSDE data should be done using an ESRI project. Consequently, the Research Team decided not to use ArcSDE. Another potential implementation that was not considered by the Research Team is to manage spatial roadway data as ArcSDE tables and restriction data as normal Oracle tables then join the tables for restriction evaluation.

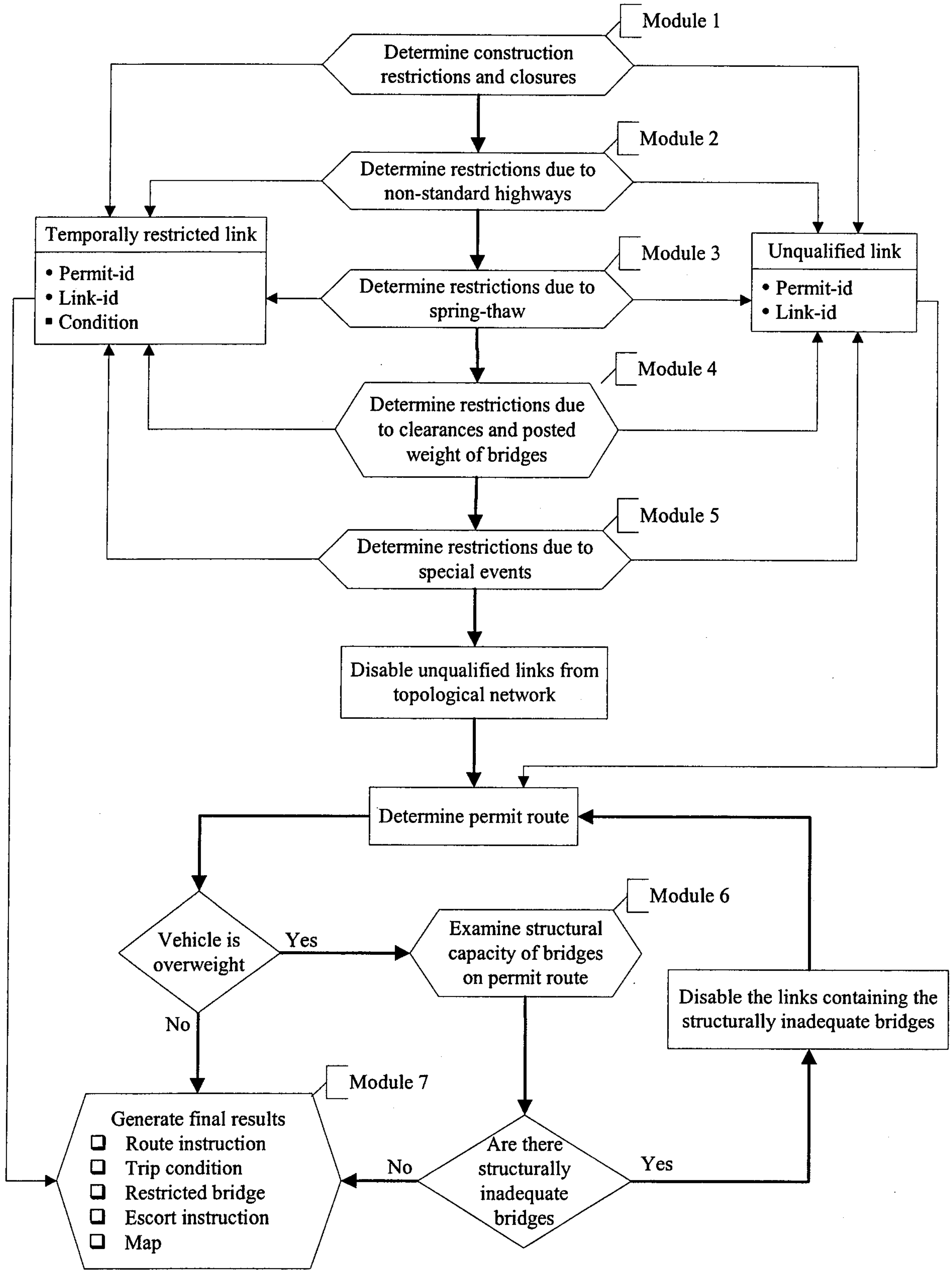


Figure 1: Main algorithm for shortest route approach

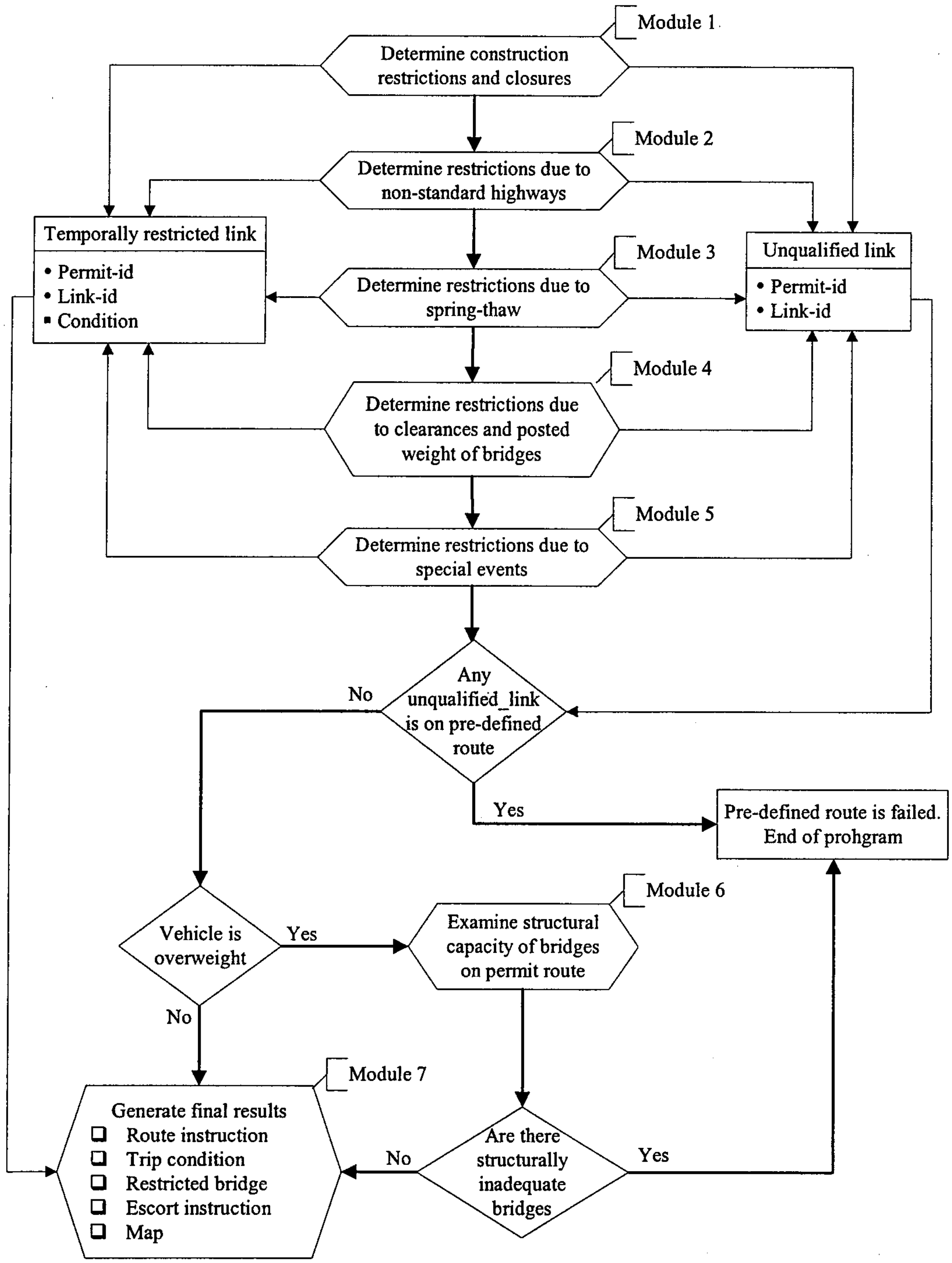


Figure 2: Main algorithm for pre-defined route approach

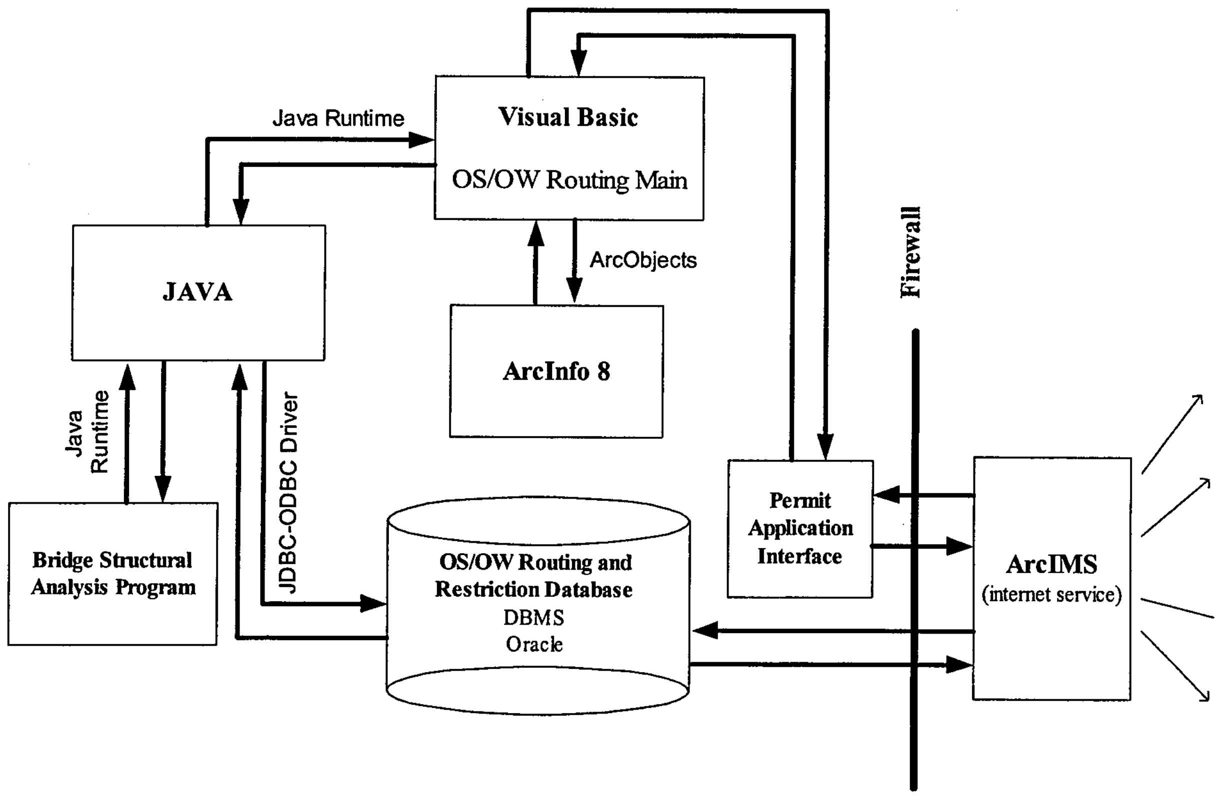


Figure 3: Software Platforms and System Architecture

2.3 Supporting Integration of Databases

Figure 4 illustrates the data model that supports the OS/OW Vehicle Routing System. It combines the topological and cartographic networks as well as the constraints, routes, and clearance margins. The model for the cartographic and topologic networks and the routes are consistent with Wisconsin DOT's current LCM data model.

The topological and cartographic networks as well as the route information are part of Wisconsin DOT's Location Control Management business area (Ries 1993). The Route and Route/Link tables are used to translate roadway links in the topological network into a human-understandable route name. A cartographic (map) representation of the permit route is generated from the chain table through the Link/Chain table.

The topological network contains roadway link impedances and nodal turning restrictions. The link impedances in this data model are real-world travel distance. A roadway link is the topological connection between two sites. A link is directed starting at the "from" site and ending at the "to" site. A site is a location where traffic can change direction. The nodal turning restrictions are embedded in the connectivity between links and sites.

Constraints describe the physical and temporal restrictions and temporary closures that occur on roadway links. Constraints may be due to construction, events, bridges, non-standard highway design, or spring-thaw. Figure 4 shows that all constraints are associated with roadway links. A set of connected roadway links comprises a permit route. All constraints on the links in a permit route must be satisfied. The data model for each type of constraint is presented in the following subsections.

Many constraints have weight limit, vertical clearance, and horizontal clearance attributes. The total vehicle weight is compared to the weight limit attribute to evaluate the constraint. The vehicle length and width are added to the clearance margins and compared to the horizontal and vertical clearances to evaluate those constraints. The clearance margins are used for the purpose of safety. There are three types of clearance margins: horizontal margin, vertical margin for oversize trucks, and vertical margin for mobile homes. Mobile homes require a larger vertical margin than oversize trucks because they tend to bounce more than other oversize vehicles.

2.3.1 Construction Projects

A construction project can cause closures and clearance restrictions on highways. A construction project can occur on multiple roadway links and a roadway link may be affected by multiple construction projects at the same or different times. Each project can cause multiple closure and clearance restrictions at various times. Each restriction occurs during a certain period of time. The start and end dates of the restriction are essential for evaluating whether the restriction applies during the two-week period when the permit is valid.

To normalize the database, the roadway links affected by construction projects are stored in the Project/Link table and the restrictions for each project are stored in the Project/Restriction table. The solid circle on the association indicates that each row in Construction restriction may be related to one row in the Construction clearance or Construction closure tables.

2.3.2 Bridges

A bridge can cause a weight or clearance restriction if a vehicle travels on or under the bridge, respectively. A bridge is a permanent constraint so no temporal reference is required. The link-id and offset from the start of the roadway link specify the bridge location. The link-id is sufficient information to disable the roadway links that possess the weight or clearance restrictions. However, the data model must contain positional information so that the driver can locate the bridge on the route. Some permits are conditional upon the driver slowing the vehicle to 5 miles per hour while crossing the bridge.

Since a bridge can carry more than one roadway link (links in opposite directions of travel across the bridge) and can cross over one or more other roadway links, a single bridge can have more than one location reference in the topological network. The multiple location references for bridges are stored in the Bridge/Link table in order to normalize the database. In the Bridge/Link table, the on/under attribute indicates the roadway link relative to the bridge. For example, roadway with link-id A, may be under bridge 01 and roadway with link-id B may be on bridge 01. In this case, bridge 01 has two locations: link A plus offset from start of link A, and link B plus offset from start of link B.

2.3.3 Non-standard Highways

A non-standard highway has narrow lane and/or shoulder width. The horizontal clearance of a non-standard highway (sum of lanes and shoulder widths) is required for the clearance evaluation. Non-standard highways are permanent constraints so no time data is required.

2.3.4 Spring Thaw

In Wisconsin, the annual spring-thaw decreases the maximum allowable load capacity of the pavement. Spring-thaw occurs during a certain period of time each year. Estimated start and end dates are essential data for evaluation of spring-thaw restrictions. Not all roadway links are affected by spring-thaw. Multiple roadway links in a geographic region are affected by spring-thaw during a single period. To normalize the database, the Spring-thaw/Link table stores the association between spring-thaw restrictions and roadway links.

2.3.5 Events

Events are temporal constraints that physically restrict or close roadway links. Temporal constraints refer to restrictions and closures for events that begin at a designated start-time and terminate at a designated end-time. The start-time and end-time may be on designated start- and end-dates. Temporal constraints can be effective daily or weekly all year-round so the designated start- and end-dates are not required. Temporary restrictions and closures can be effective on a single day or for a duration over multiple days.

Events are classified into 5 categories: temporary restriction, temporary closure, daily restriction, weekly restriction, and seasonal restriction. The categories are defined according to whether the constraint causes a restriction or closure, whether the restriction has designated start- and end-dates, and whether the constraint has a weekly or daily cycle. Our conceptual model allows for all combinations, however in our relational database implementation, all combinations are not accommodated. Highways may be temporarily closed or restricted for a period of time on a one-time, daily, or weekly basis. For example, daily rush hour congestion may cause daily restrictions. Seasonal weekend tourist traffic may cause a highway to be restricted weekly during the summer months. For example, a seasonal restriction may begin Friday afternoon and end Sunday afternoon during the summer tourist season between Memorial Day and Labor Day. Finally, a parade may cause a roadway to be closed to all traffic for a specific period of time.

Events can occur on several roadway links or a roadway link can be affected by multiple events at the same or different times. Thus the roadway links affected by events are stored in the Event/Link table in order to normalize the database.

2.3.6 Escorts

Some local jurisdictions require an escort for OS/OW vehicles on certain roadways. The Escort requirement table contains instructions for obtaining an escort vehicle. Escort instructions are associated with roadway links through the Escort/Link table.

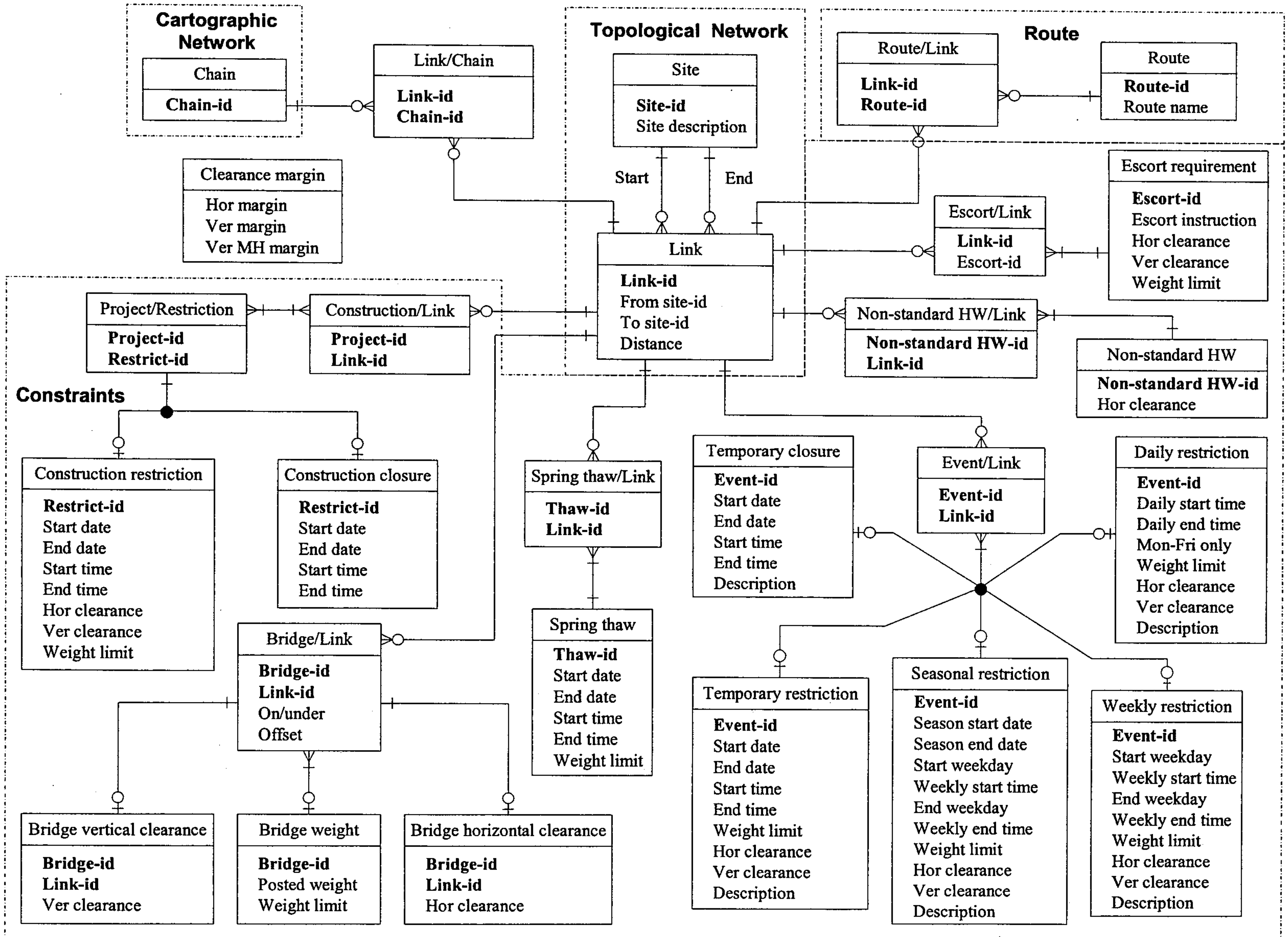


Figure 4: OS/OW Routing and Restriction Database Schema

3 APPLICATION MANUAL

This section serves to guide the implementation and operation of the OS/OW Vehicle Routing System. This section also illustrates some of the current capabilities of the system and the results generated from the application.

3.1 Data Preparation

The OS/OW Vehicle Routing System generates routes between origin and destinations. Route generation requires ArcInfo version 8 or higher. The ArcInfo Utility Network Analysis tool generates the routes on a network that is modeled as a one-dimensional nonplanar graph (geometric network) composed of features.

Geometric networks have topological relationships between edge and junction features (McDonald, 1999). A geometric network is built from existing simple features is performed in ArcCatalog. Refer to McDonald (1999) for more information. The following steps build the geometric network. Updates and edits can be achieved directly on the finished network

1. Create a new personal geodatabase.
2. Define feature datasets and feature classes. Coverages from the STN ("rdwy_chn", "rdwy_link" and "ref_site") are imported to the geodatabase as feature classes. The chain coverage "rdwy_chn" from STN needs to be imported first, so that the projection for the new feature dataset is defined implicitly.
3. Create the geometric network within the geodatabase by using the wizard:
   a. Select rdwy_link and ref_site as feature classes to build the network.
   b. No complex edges and no features are snapped.
   c. No sources or sinks.
   d. An important step during network creation is to define the weights (cost of traveling along a link or edge) since these cannot be added after the network has been created. Three weights need to be entered as integers ("along_digit", "against_digit" and "status") and assigned to the corresponding fields in the rdwy_link attribute table. The "along_digit" weight corresponds to the "from_to_dist" field in the rdwy_link attribute table. Both "against_digit" and "status" weights relate to fields that must be added to the rdwy_link attribute table. The against digitization field has a value of –1 for all records. This value is used by ArcInfo8 to prohibit flow in the against digitization direction. The status field has a value of zero for current links and a value of –1 for historical links. In this case, a value of –1 represents links not to be employed during the route generation. ArcMap defines the direction of links according to the digitized direction.

Reference sites are used to designate trip origins and destinations. Therefore, x and y coordinates must be added to the ref_site attribute table to position each reference site on the map provided in ArcMap. Multiple codes for GIS tools can be found to determine coordinates of features located within a map. The following website provides a code called "addxy" needed for this purpose: http://gis.esri.com/arcscripts/scripts.cfm

3.2 Application Operation

This subsection describes the step-by-step actions to execute the OS/OW Vehicle Routing System application. Certain network analysis options, however, need to be pre-configured before the application can be executed.

3.2.1 Pre-configuration Process

In ArcMap, add the Utility Network Analyst toolbar, if it is not available. Using this toolbar, under Analysis, select Options, then select the Weights tab. Under Edge Weights, select the "along_digit" field for the weight along digitized direction of edges ("From_To" links). Leave the other options as "none". Click on the Weights Filter tab. Under Edge Weight Filter, select the "Status" field for the "From_To" weight, and the "against_digit" field for the "To_From" weight and type 0 (zero) at the weight range. Under the Results tab, select "Selection" for the return results in the Results Format, and check only Edges in the Results Content. For more information refer to Minami et al. (1999).

This project can be saved and used in the future without loading the network again. However, changes on the Utility Network Analyst toolbar menu must be made every time the project is opened.

3.2.2 Step-by-step Operation of the OS/OW Vehicle Routing System

Step 1: Open the project file created in the pre-configuration process in ArcInfo Desktop.

Step 2: Run the application by clicking on the "happy face" ☺ icon. The user also has an option to call the application directly by running the "newmacros" module written in the Microsoft Visual Basic. Once the application starts, the "permit application" panel (Figure 5) appears.

Step 3: Enter the permit information into the "permit application" panel and click "OK" to continue. Then the "type of route" panel (Figure 6) appears. If the user wants to start over again, click "Cancel".

Step 4: Select type of route by clicking on either the "shortest route" or "predefined route" button. The "shortest route" approach provides the optimal solution while the "predefined route" approach provides a safer predefined route for OS/OW vehicles.

Step 5: If the "shortest route" button is clicked, then the "shortest route" panel (Figure 7) appears. The user then selects the origin and destination (from the drop-down menu) of the route from this panel. Then click "OK" to continue.

If the "predefined route" button is clicked, then the "predefined route" panel (Figure 8) appears. The user then selects the pre-defined route from the drop-down menu. Click "OK" to continue.

Step 6: Once the origin and destination or the predefined route is selected, then the application brings back the "type of route" panel again. Then the user simply clicks the "Execute" button to run the application.

Step 7: For the "shortest route" approach, if a route is found, the application generates the permit-route map as well as the route instructions. Additional instructions such as restricted bridge or escort restrictions are also generated if they are applicable. Instructions can be found in the "C:\oopps_temp" directory. Further details and examples of results from the application are in the following subsection. If a route is not found, then the program terminates and an error message notifies the user that a route is not found.

For the "predefined route" approach, the permit-route map and the route instructions are generated if the route is approved. Similar to the "shortest route" approach, additional instructions such as restricted bridge and escort instructions are also generated if the they are applicable. If the route fails, then the application terminates and an error message notifies the user that the pre-defined route is not approved. Additionally, the application generates a summary of the restrictions on the pre-defined route if the pre-defined route fails.

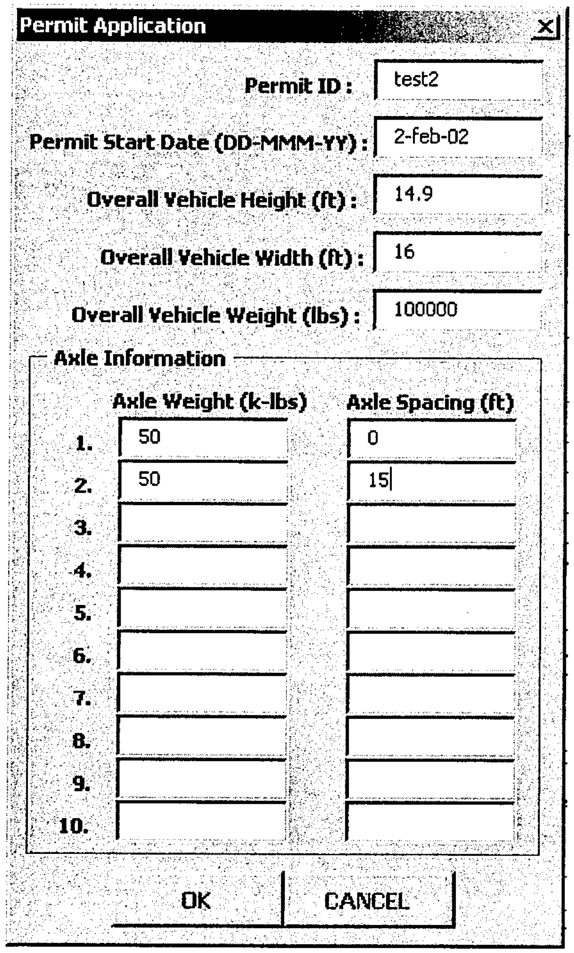


Figure 5: Permit application panel

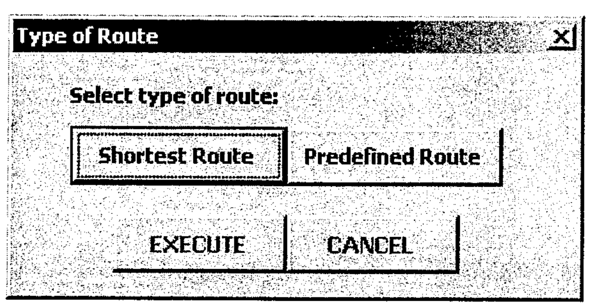


Figure 6: Type of route panel

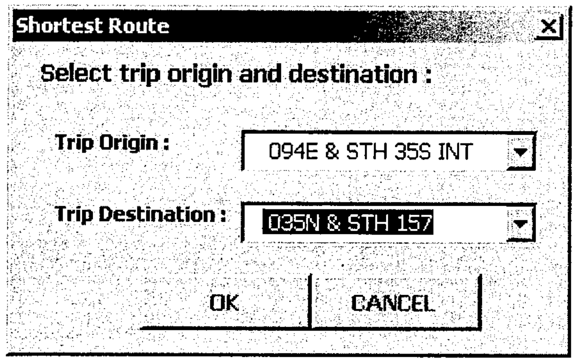


Figure 7: Shortest route panel

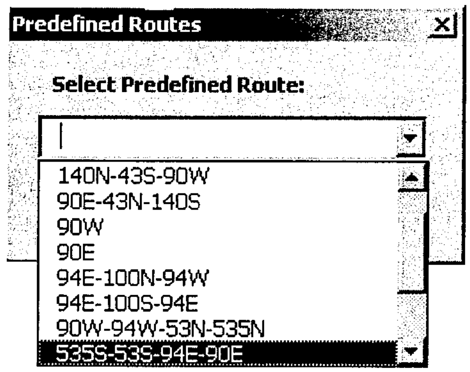


Figure 8: Predefined route panel

3.3 Application Outputs

After executing the application as described in the previous section, a cartographic map is delivered to the motor carrier along with detailed route and escort instructions; and temporal and bridge restrictions.

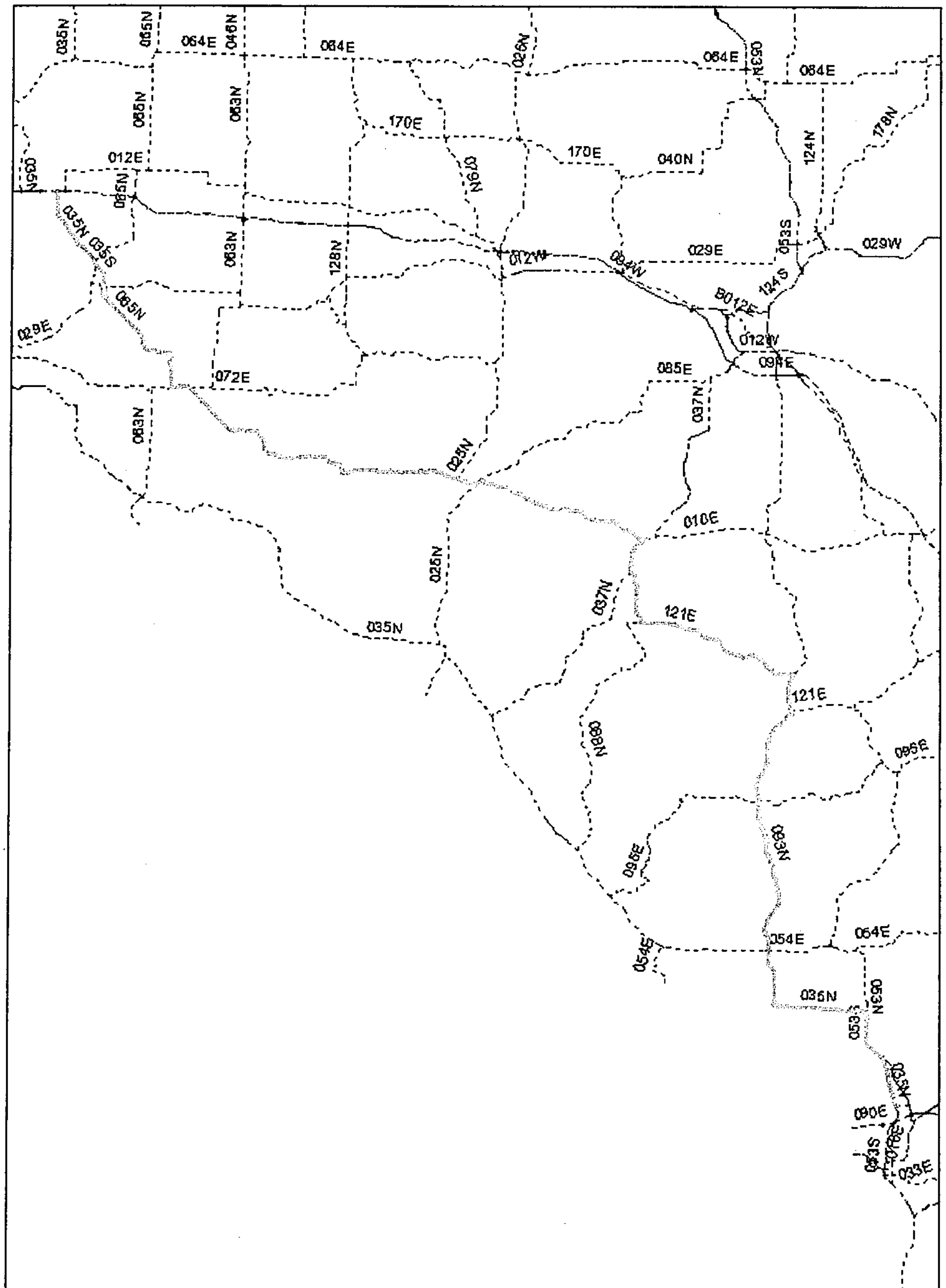
The cartographic map shown in Figure 9 presents the shortest route in a solid line between the trip origin and destination indicated in Figure 7. Additionally, the application generates system information for the Motor Carrier Division and Bridge section including a restriction summary and a list of bridges that are not in the bridge structural database.

Figure 10 illustrates the route instructions for the example route in Figure 9. These instructions provide the motor carrier with exits, route numbers, and distances along the roadways from origin to destination.

Figure 11 illustrates the escort instructions along the permit route.

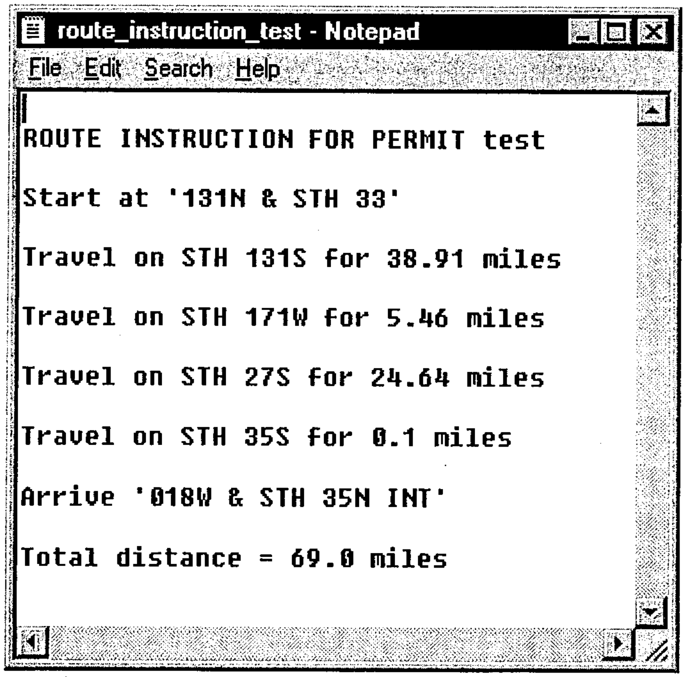
Figures 12 and 13 present examples of temporal and bridge restrictions, respectively. Figures 14 and 15 show examples of the disqualified links summary and a list of bridges not contained in the database, respectively that are available to the DOT personnel.

OS/OW Route Permitting Map



Permit-ID test2 Origin 094E & STH 35S INT
Effective Date 2-Feb-02 Destination 035N & STH 157

Figure 9: Example map output showing shortest route



route_instruction_test - Notepad

File Edit Search Help

ROUTE INSTRUCTION FOR PERMIT test

Start at '131N & STH 33'

Travel on STH 131S for 38.91 miles

Travel on STH 171W for 5.46 miles

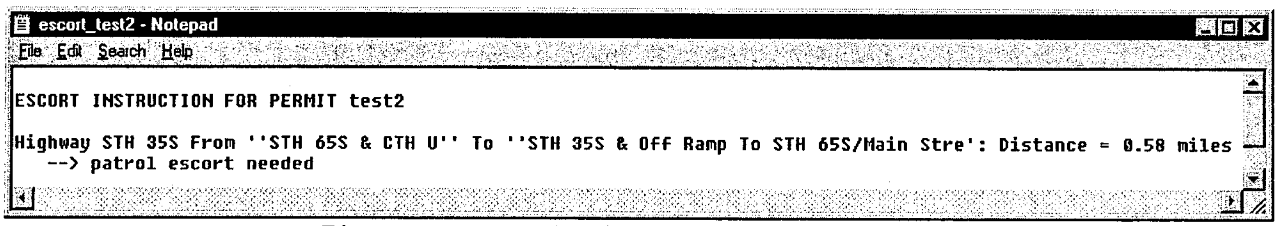
Travel on STH 27S for 24.64 miles

Travel on STH 35S for 0.1 miles

Arrive '018W & STH 35N INT'

Total distance = 69.0 miles

Figure 10: Example of route instruction output



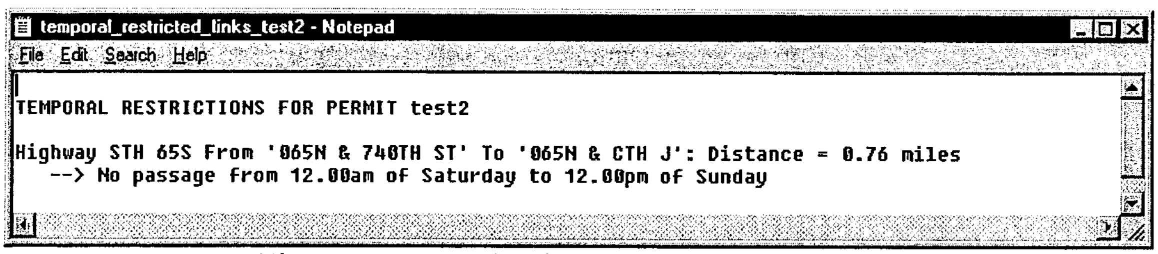
escort_test2 - Notepad

File Edit Search Help

ESCORT INSTRUCTION FOR PERMIT test2

Highway STH 35S From ''STH 65S & CTH U'' To ''STH 35S & Off Ramp To STH 65S/Main Stre': Distance = 0.58 miles
--> patrol escort needed

Figure 11: Example of escort instruction output



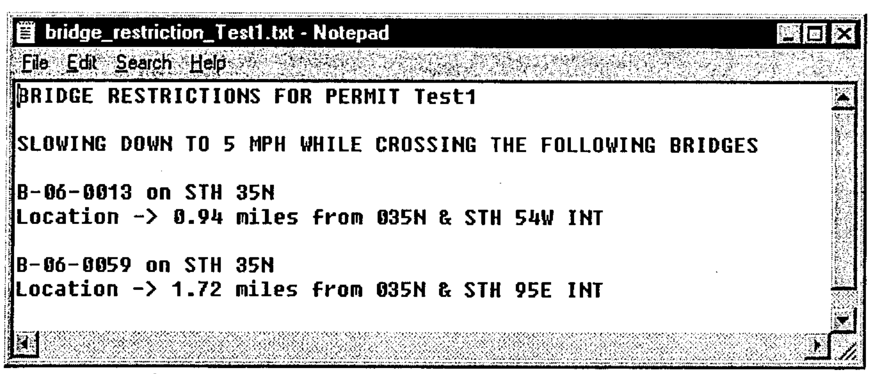
temporal_restricted_links_test2 - Notepad

File Edit Search Help

TEMPORAL RESTRICTIONS FOR PERMIT test2

Highway STH 65S From '065N & 740TH ST' To '065N & CTH J': Distance = 0.76 miles
--> No passage from 12.00am of Saturday to 12.00pm of Sunday

Figure 12: Example of temporal restriction output



bridge_restriction_Test1.txt - Notepad

File Edit Search Help

BRIDGE RESTRICTIONS FOR PERMIT Test1

SLOWING DOWN TO 5 MPH WHILE CROSSING THE FOLLOWING BRIDGES

B-06-0013 on STH 35N
Location -> 0.94 miles from 035N & STH 54W INT

B-06-0059 on STH 35N
Location -> 1.72 miles from 035N & STH 95E INT

Figure 13: Example of bridge restriction output

```
restriction_test10 - Notepad
File  Edit  Search  Help

DISQUALIFIED ROADWAY SECTIONS FOR PERMIT test10

No passage on Highway STH 35N From '035N & CTH UU INT' To '035N & KRATTLEY LANE'
   --> Due to 'bridge vertical clearance restriction'

No passage on Highway STH 35S From '035N & KRATTLEY LANE' To '035N & CTH UU INT'
   --> Due to 'bridge vertical clearance restriction'

No passage on Highway USH 63S From '063N & CTH KK INT' To '063N & CTH V'
   --> Due to 'construction closure'

No passage on Highway USH 63S From '063N & CTH K INT' To '063N & CTH KK INT'
   --> Due to 'construction closure'

No passage on Highway Ramp 885 From 'R94E & Connector to R43N' To 'R094E & ON RAMP FROM I 794W'
   --> Due to 'bridge vertical clearance restriction'

No passage on Highway Connector 890 From 'R94E & Connector to R43N' To 'R43N & Connector from R94E'
   --> Due to 'bridge vertical clearance restriction'
```

Figure 14: Example of summary restrictions output

```
bridges_not_in_DB_test10.txt - Notepad
File  Edit  Search  Help
B-61-0029
B-61-0019
B-61-0012
B-55-0137
B-55-0135
B-47-0134
B-47-0133
B-32-0150
B-32-0148
B-32-0142
B-32-0018
B-32-0016
B-06-0890
B-06-0889
B-06-0095
B-06-0066
B-06-0059
B-06-0028
B-06-0018
B-06-0017
B-06-0016
B-06-0015
B-06-0014
B-06-0013
```

Figure 15: Example of list of bridges not in the bridge structural analysis program database

4 EVALUATION OF BRIDGE DATA

4.1 Bridge Evaluation Program

Bridge Evaluation Program (BEP) was developed to automatically: 1) find the link/site addresses for bridges in the Bridge Log; and 2) detect discrepancies between bridges in Bridge Log and in the STN inventory. Bridge Log is the bridge file with complete and reliable data for oversize/overweight route permitting evaluation. The analysis presented in the section is based upon link/site addresses on the topological network of bridge locations in WisDOT's STN inventory.

BEP is a series of integrated MS Access queries. The following are six discrepancy types (as graphically illustrated in Figure 16) that can be detected by BEP. These discrepancies are not necessarily errors; they are inconsistencies that should be investigated before the STN inventory of bridges can be used to support OS/OW routing.

1) *Commission Bridges.* Bridges that are contained in the STN inventory but do not exist in the Bridge Log, are classified as Commission Bridges. The Bridge Log contains bridges with codes B (state bridge), S (sign bridge), and P (built-but-no-plan bridge) structures. The STN inventory also contains C (culvert), R (retaining wall), and N (noise barrier) structures. BEP does not evaluate C, R, and N structures because they are out of scope of the Bridge Log.
2) *Missing Bridges.* Missing Bridges are bridges that exist in the Bridge Log but are not contained in the STN inventory. The BEP analysis is based upon locations of the bridges in the STN inventory as Links and offsets rather than RPs and offsets. Using Link and offset addresses eliminates the possibility of identifying erroneous missing bridges (or repeated bridges, see discrepancy type 6 below) because of multiple concurrent routes.
3) *Un-updated Bridges.* STN contains both historic and current links. Un-updated Bridges are bridges in the STN inventory that are referenced to historic rather than current links.
4) *On/Under Conflict Bridges.* On/Under Conflict Bridges are bridges in the STN inventory that have an On/Under status that conflicts with the On/Under status of the bridge in the Bridge Log.
5) *Repeated Bridges.* Repeated Bridges occur in the STN-Bridge dataset where there is more than one record of the bridge on a route. BEP uses entire bridge-id (the 1st letter, 2 digit county code, 4 digit bridge number, and an optional 4 digit number for the span) to avoid identifying bridges with multiple spans as repeated bridges. Figure 17 illustrates a situation where a repeated bridge is not an error. B-13-0016 occurs on USH 151N twice. A vehicle traveling on USH 151N first goes over B-13-0016 and then goes under B-13-0016. BEP uses the following criteria to determine errorneous repeated bridges.
   - There are more than two records for a bridge on one route in the STN inventory.
   - A bridge is repeated in the STN inventory but not repeated in the Bridge Log.
   - The sequence of On/Under status of the repeated bridge in STN inventory does not conform to the sequence of On/Under Status of the repeated bridge in the Bridge Log.
6) *Incorrect Sequence Bridges.* Two or more bridges in the STN inventory with a bridge-to-bridge sequence that is different from the bridge-to-bridge sequence in the Bridge Log are Incorrect Sequence Bridges.

Bridge-ids are used by BEP to compare bridges in the STN inventory with bridges in the Bridge Log. Errors of the types, Commission Bridges, Missing Bridges, On/Under Conflict Bridges, and Incorrect Sequence Bridges may be attributed to incorrect bridge-ids in the STN inventory. For example, if the field data collector obtained incorrect bridge-ids, the result may contribute to Commission Bridges and Missing Bridges as well as On/Under Conflict Bridges.

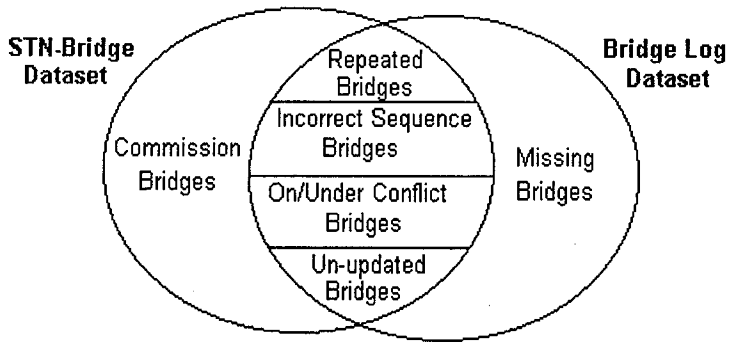


Figure 16: Error Type in STN-Bridge Dataset

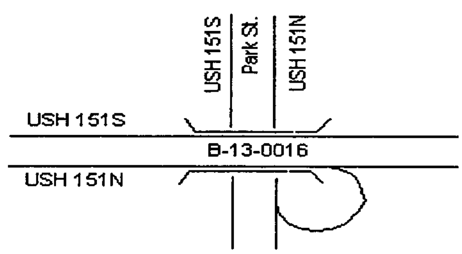


Figure 17: Repeated Bridges on USH 151N

The beginning points of bridges typically represent the locations of bridges in the STN inventory. For some bridges, however, both the beginning and ending points represent the locations. The BEP tool ignores the ending locations of the bridges in the evaluation to avoid misleading results.

In the STN inventory, a bridge may be referenced to only one of two concurrent links that have opposite direction when the bridge actually occurs on both links. The STN frequently references these bridges to only the concurrent link in the cardinal direction not both. Before evaluating bridges on a non-cardinal (cardinal) route, BEP references the bridges to the concurrent cardinal (non-cardinal) links to the non-cardinal (cardinal) route.

BEP evaluates bridges on mainline routes (IH, USH, and STH) only. Bridges on off-mainline routes or on reference routes (ramps, connectors, etc.) are not evaluated by BEP because human interpretation is required to correlate the off-mainline routes in the STN with the reference routes in the Bridge Log. For example, Reference 28 in the Bridge Log is a combination of rdwy_link 32840 (part of 2716 connector), rdwy_link 32842 (part of STH 69N), and rdwy_link 29080 (part of ramp 1334) in the STN. BEP cannot automatically correlate Reference 28 with the off-mainline routes in the STN.

Evaluation Results for STH 35

This section presents the summary of the bridge evaluation results on STH 35 from the BEP tool. Table 1 presents the numbers of bridges on STH 35 contained in the Bridge Log and STN inventory while Table 2 presents the numbers of discrepancies.

Table 1: Numbers of Bridges on STH 35

Source	STH 35N	STH 35S
Bridge Log	120	123
STN	125	103

Table 2: Number of discrepancies between STN and Bridge Log

Discrepancy Type	STH 35N	STH 35S
Commission Bridges	22	4
Missing Bridges	15	23
Un-updated Bridges	3	3
Repeated Bridges	2	7
On/Under Conflict Bridges	2	5
Incorrect Sequence Bridges	2	0
Total Discrepancies	46	42

Figures 18 and 19 illustrate the portion of each discrepancy type as a percentage of the total number of discrepancies of STH 35N and STH 35S, respectively. As can be seen, Missing Bridges and Commission Bridges dominate the entire discrepancies. Figure 20 shows each discrepancy type as a percentage of the number of bridges in the STN inventory. Figure 20 illustrates the quality of the bridge data contained in the STN inventory. Missing Bridges discrepancy are not shown in Figure 20. Instead, Missing Bridges discrepancy is shown in Figure 21 as the percentage of the number of bridges in Bridge Log.

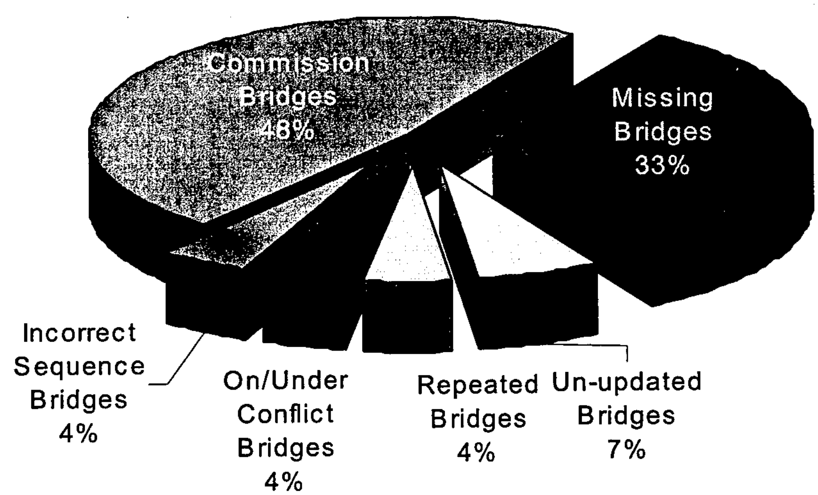


Figure 18: Distribution of Discrepancies on STH 35N

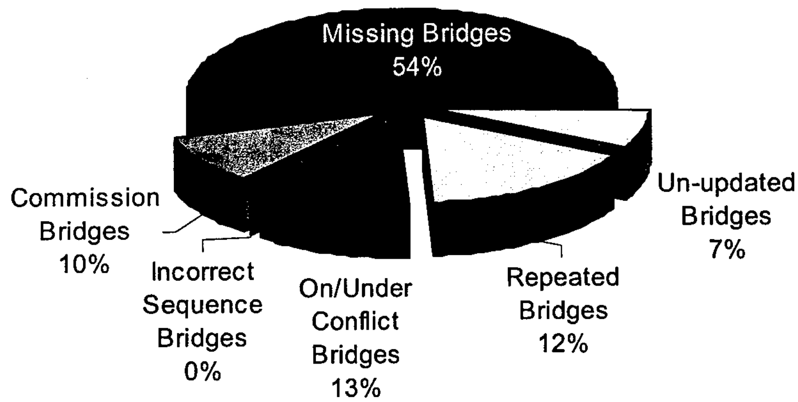


Figure 19: Distribution of Discrepancies on STH 35S

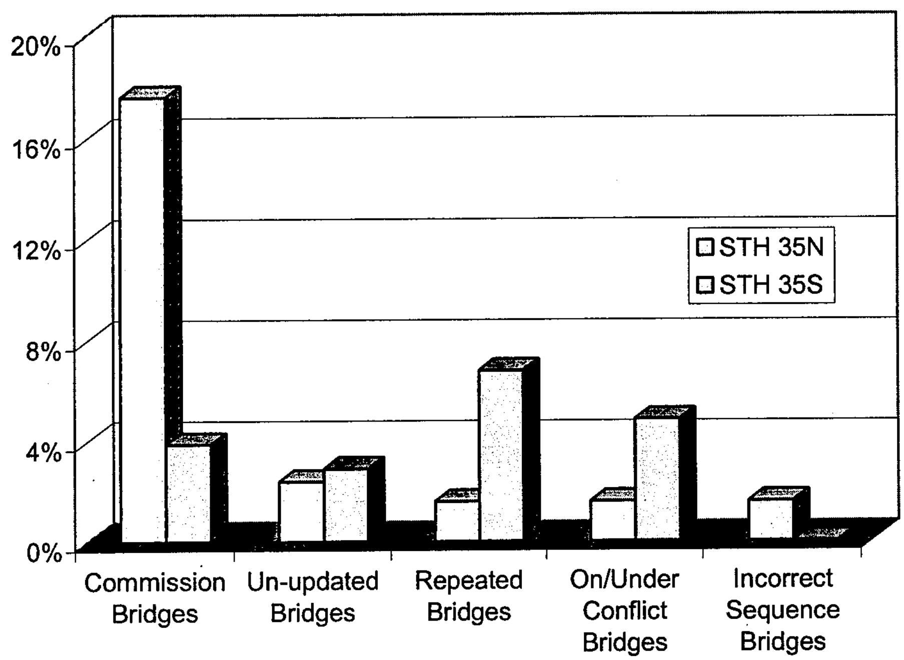


Figure 20: Discrepancies on STH 35 as a percentage of STN Records

The Bridge Log contains bridges on local roads, which cross over state highways. Figure 22 illustrates an example of a local bridge that is contained in the Bridge Log. It was anticipated that the STN does not contain such bridges and these bridges are the main reasons of missing bridges.

However, it was later found that the anticipation above is not correct. Bridge Log contains 2,444 records of local bridges. One thousand eight hundreds and twenty records of these bridges are found in the STN inventory. In other words, roughly 75% of local bridges in the Bridge Log are contained in the STN. In addition, regarding to the Missing Bridges on STH 35, only 4 out of 15 Missing Bridges on STH 35N and 5 out of 23 Missing Bridges on STH 35S are local bridges.

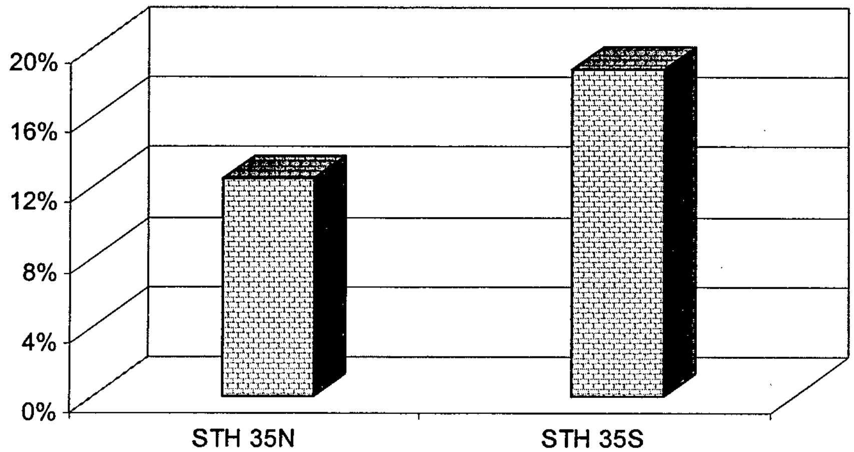


Figure 21: Missing Bridges on STH 35 as a Percentage of Bridge Log Records

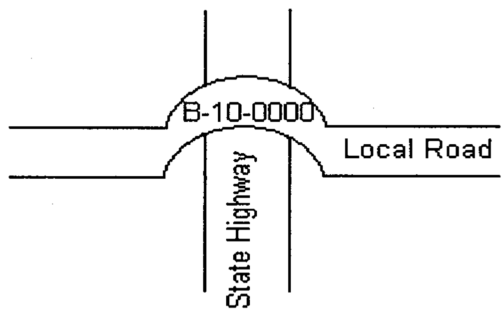


Figure 22: Bridge on Local Road contains in Bridge Log

4.2 Evaluation Results for the Marquette Interchange

This section presents the summary of the bridge evaluation results for the Marquette Interchange from the BEP tool. Table 3 presents the numbers of bridges on- and off-mainlines at the Marquette Interchange that are in the Bridge Log and STN inventory. Table 4 presents the numbers of discrepancies of bridges in the Bridge Log and STN inventory at Marquette Interchange.

Table 3: Bridges at Marquette Interchange

Source	On-mainlines	Off-mainlines
Bridge Log	60	32
STN	57	27

Figures 22 and 23 illustrate the portion of each discrepancy type as a percentage of the total number of discrepancies on- and off-mainlines at Marquette Interchange, respectively. Figure 24 shows each discrepancy type as a percentage of the number of bridges in the STN inventory and provides a measure the quality of the bridge data contained in the STN inventory. Missing Bridges discrepancy are not shown in Figure 24. Instead, Missing Bridges discrepancy is shown in Figure 25 as the percentage of the number of bridges in Bridge Log.

Table 4: Number of discrepancies at Marquette Interchange

Discrepancy Type	On-mainlines	Off-mainlines
Commission Bridges	1	7
Missing Bridges	6	11
Un-updated Bridges	0	0
Repeated Bridges	4	0
On/Under Conflict Bridges	0	0
Incorrect Sequence Bridges	11	5
Total Discrepancies	22	23

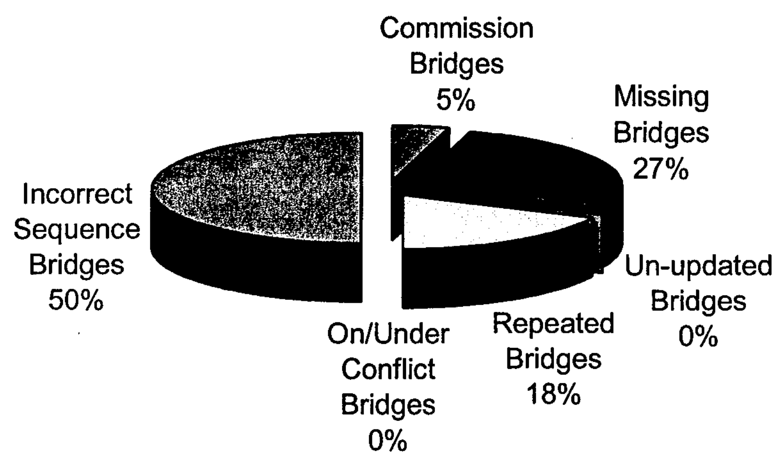


Figure 22: Distribution of Discrepancies on Mainlines at Marquette Interchange

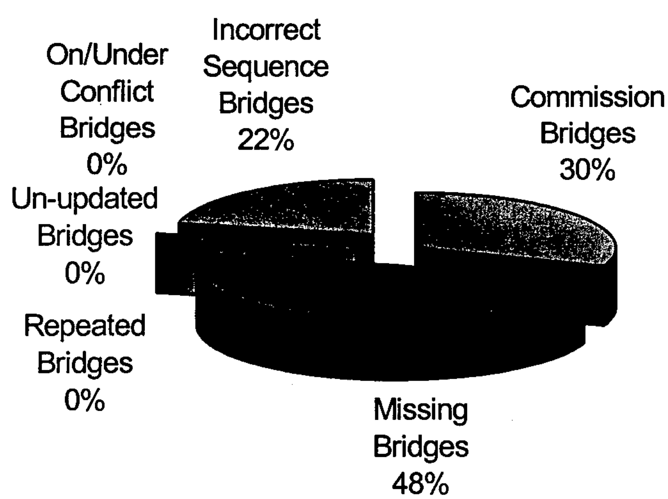


Figure 23: Distribution of Discrepancies on Off-mainlines at Marquette Interchange

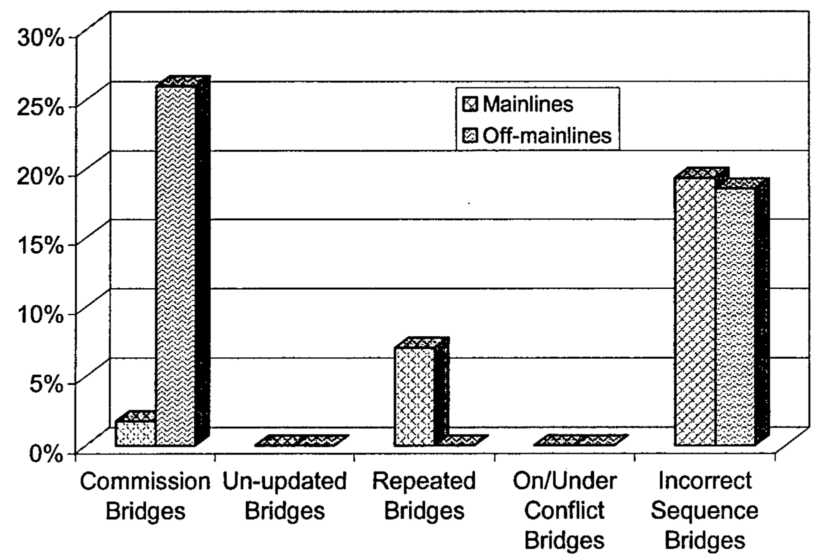


Figure 24: Discrepancies as a percentage of STN Records

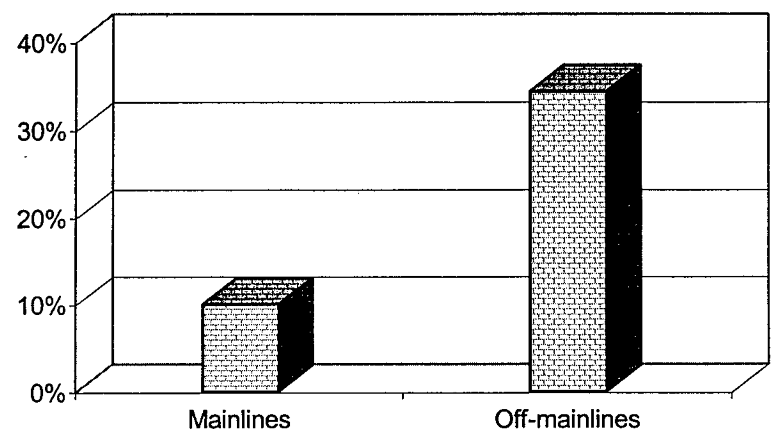


Figure 25: Missing Bridges as a Percentage of Bridge Log Records

4.3 Techniques for Resolving Bridge Location Discrepancies

The research team investigated alternative techniques to resolve discrepancies in bridge data sources. Several practicable methods include field data collection of linear location references or GPS coordinates of bridge locations; and estimating the bridge locations using aerial photograph and descriptive location along with the bridge-to-bridge sequence in the Bridge Log. Each solution has advantages and disadvantages as described below.

4.3.1 Linear Location References

Field data collecting is a procedure to go out in the field to collect the data that can be used to resolve the discrepancies between Bridge Log and STN inventory. The types of discrepancy include Missing Bridge, On/Under Conflict Bridge, Repeated Bridge, and Incorrect Sequence Bridge.

The field data collecting requires making measurements from known points to bridges. So the accuracy of measurement result is dictated by the resolution and accuracy of measurement device. For example, two different devices have different resolutions. The first device can measure up to one tenth of a mile while the second device can measure up to one hundredth of a mile. So it is obvious that the second device can provide a better measurement result than the first device as long as the two devices have the same accuracy. Accuracy of device is referred to how accurate a device can measure. For example, two different devices have different accuracy. The accuracy of the first device is within 1 ft/mile while the accuracy of the second device is within 2 ft/mile. So the first device clearly can provide a better result.

DMI (Distance Measurement Instrument) may be used as measurement device because it can provide accurate result. However, DMI is extremely sensitive particularly to temperature. So it is needed to be calibrated rather often (normally DMI is supposed to be calibrated twice a day).

For the ease of calibration and measurement, an odometer of a car can be used to make measurement. However, it is obvious that the accuracy of result from an odometer is certainly less accurate than the result from DMI. It should be noted that an odometer should be calibrated periodically.

The discrepancies must be detected before going out in the field. The BEP tool can automatically detect the discrepancies. Each type of discrepancy requires different data and observation to resolve the problem. For On/Under Conflict Bridge, a data collector simply observes the On/Under Status of the bridge. For Incorrect Sequence Bridge, the data collector simply observes the sequence of bridges, which are listed as Incorrect Sequence Bridge by the BEP tool. For the Missing Bridge and Repeated Bridge, the measurement from a known point to the bridge is required and consequently the new Link/Site address of the bridge is determined.

Missing Bridge means the bridge is in the Bridge Log but not in the STN inventory. So the Link/Site address of the bridge is missing. The Link/Site address of the bridge can be determined by an offset measured from a known point to the bridge or measured from the bridge to a known point. A known point is an easily identifiable point, whose RP (Reference Point) or Link/Site address is already known. A known point can be a known bridge or an RP. Once the offsets are determined, a post-processing step determines the Link/Site address of the bridge.

The measurements should be made from a known point to both the beginning and the ending of the bridge. Determination of accuracy requirements for measurements is beyond the scope of this project. Generally, bridges must be located on the correct link and in the correct sequence. Furthermore, bridges should be positioned accurately enough so that when a local road splits the links, bridges are correctly assigned to the appropriate link segment that occurs before or after the intersection with the local road.

It should be noted that the measurement should be made from a known point to the bridge rather than from the bridge to a known point. If the measurement is made from the bridge to the known point, the offset will be negative. WisDOT's LCMCONVERT tool was not designed to handle negative offsets for RPs. (The LCMCONVERT tool is the tool that can automatically find the Link/Site address of the bridge using the offset from a known RP.) If the offset is negative, the Link/Site address can be determined by a manual data approach instead of using the LCMCONVERT tool. This is neither a technical limitation nor a limitation of the LRS. As LCMCONVERT is migrated to run on ArchInfo8.X and against Oracle and ArcSDE data, this functionality can be included (personal communication with JJ. DuChateau, WisDOT on April

12, 2002). Further explanation of direction of offset as well as the conversion from offset to Link/Site address is described in Appendix III of Adams et al. 2000.

Bridge Log has descriptive locations of bridges. The data collector may use these descriptive locations in the planning process for field data collecting. Furthermore, the data collector should determine the known points before going out to the filed. This will make the data collecting process easier.

For a divided highway, the data collecting process must be done twice, one on each direction of the highway. For a non-divided highway, the data collecting process may be done only once because the data in both directions can be collected at the same time. However, the cost of less field data collection is more work in post-processing step. Additionally, errors and mistakes occurring during data collecting process and post-processing step are likely to increase. Example of collecting data on a non-divided highway can be seen in the Bridges on STH 35 report.

Some bridges, particularly sign bridges, do not have bridge-ids posted on them. This causes a problem during the data collecting process. Unless there is another way to find the bridge-ids, the data collector may use the sequences of bridges in Bridge Log to determine the bridge-ids. (Presumably the bridge-to-bridge sequences in Bridge Log are correct.)

4.3.2 GPS Coordinates

Coordinates of bridges collected by GPS receivers are fairly accurate in terms of global position (where on earth a bridge is). However, these coordinates have limited accuracy in term of relative position. In other words, bridges may not lie on the corresponding roadways. The research team completed a comparison of bridge locations from GPS coordinates and Link/Site addresses for District 5. The bridge locations from both methods were plotted on the cartography of the roadway (roadway chain network). In that experiment, the bridge locations from GPS coordinates lied on neither the corresponding roadways nor bridges from Link/Site addresses. This happened because of four possible error sources:

1. *Error is GPS measurements.* GPS measurements contain error. The significance of error depends on the GPS system for measurement (Differential GPS, stand-alone GPS, etc.)
2. *Error in Link/Site addresses.* Link/Site addresses contain some error.
3. *Accuracy of the cartography of roadways.* The roadway cartography meets National Map Accuracy requirements for 1:100,000 line work (personal communication with Mike Krueger, WisDOT). Accordingly, cartography of the roadway is accurate to +/-167 feet.
4. *Different measuring locations between the two systems.* GPS coordinates were taken in the MIDDLE of the bridge regardless the highway is ON or UNDER the bridge. STN inventory collection rules specify that the location references be taken a the BEGINNING of the bridge if the highway is ON the bridge; and at the MIDDLE of the bridge if the highway is UNDER the bridge.

The use of GPS coordinates requires further study to find the technique to automatically snap the bridges to the roadways especially at complex intersections such as Marquette Interchange. It should be noted that only GPS coordinates of bridges could not resolve the On/Under Conflict discrepancy.

4.3.3 Aerial Photographs and Descriptive Location

This is another technique that can be used determine the Link/Site addresses of bridges. In this technique, the descriptive location in the Bridge Log is used to locate the bridge on the aerial photograph that has reference points. By referring to the reference point to which the bridge is referenced, the predecessor and successor bridges can be determined from the STN log. If the predecessor and successor bridges do not confirm the bridge-to-bridge sequence in the Bridge log, then the location of the bridge is not correct. The bridge is then arbitrarily moved to correspond to the bridge-to-bridge sequence in the Bridge Log. In the case that the descriptive location of the bridge in the Bridge Log is ambiguous, the bridge might be arbitrary located between the predecessor and successor bridges as stated in the Bridge Log. The accuracy of the results from this technique is based upon human interpolation and the accuracy of the Bridge Log. It should be noted that the aerial photography might contain some distortion from the photocopy process.

5 ROUTING RESTRICTION DATA REQUIREMENTS

This section describes the data requirements for populating the restriction database. Determination of link/site addresses of restrictions appears to be the major work effort for populating the restriction database. Nonetheless, the work can be accomplished automatically or manually depending on the availability and accuracy of the data.

Location references using the Route, RP, and Offset method are one mechanism to enter the linear location of data of a restriction. This is the primary method that was considered for this research project. Another method is the On/At reference (newly available in WISLR) that uses road names and intersections. A third method that is currently available is point and click on a map. All of these methods are means that an end-user can conveniently position restriction information along a roadway. WisDOT's LCMCONVERT tool can be used to transform the position to a Link/Site address.

5.1 Bridge Restrictions

Bridges are vital in the evaluation of the restrictions for an OS/OW vehicle. A bridge may cause weight, height, and/or width restrictions. One needs to know not only the maximum capacity and clearances of each bridge, but also the location of the bridge on the roadway network and the type of association between a bridge and roadway. One needs to know whether a roadway goes over or under the bridge in order to apply the appropriate evaluation to the bridge. The essential data that are required for each bridge are listed as follows.

Bridge-id. This is simply identification for a bridge.

Link/Site address (link-id & offset) of bridge. The Link/Site address of a bridge identifies the bridge's position on the roadway network. The Link/Site address is a combination of a link-id and an offset distance from the starting point of the link (From Site) to the location of the bridge.

The Link/Site address can be transformed to the Reference Point (RP) address. The RP address is more easily recovered in the field. An RP address is a combination of an RP, a route associated with the RP, and an offset from the RP to the location of the bridge. The RP address, in fact, provides the means for field data collection of the bridge locations.

The RP address can be converted to the Link/Site address (and vice versa) through WisDOT's LCMCONVERT tool. To convert an RP address to a Link/Site address, one needs to know not only the RP and an offset, but also the route designation associated with the RP since the RP is route dependent, meaning that one RP can be used in two or more different routes.

On/Under status. *A*ssociations between bridges and roadways indicate at what locations roadways travel on or underneath bridges. If a permit route goes over a bridge, weight and occasionally clearance restrictions need to be verified. Weight evaluation of a bridge is not needed if the permit route travels under the bridge.

Allowable vertical and horizontal clearances. A bridge with a roadway traveling underneath must have an allowable vertical clearance value. An allowable horizontal clearance value is required for narrow bridges and bridges with horizontal constraints.

Posted weight. Certain bridges name posted maximum allowable weights. A vehicle with overall-weight greater than the posted weight is prohibited from crossing the bridge.

Maximum Vehicle Weight (MVW) Rating. MVW rating is needed for comprehensive analysis of the bridge structure. Bridges with MVW rating less than the overall-vehicle weight need to be evaluated by the structure analysis program.

WisDOT has two sets of bridge data: Bridge Log and STN inventory. The Bridge Log can be used to populate the bridge database since it contains the essential data that are required for the evaluation of bridge restrictions. However, the Bridge Log lacks Link/Site addresses for positioning bridges on the roadway network. The Link/Site addresses of bridges can be obtained from the STN inventory.

The Link/Site addresses of bridges in the Bridge Log can be automatically determined using the BEP (Bridge Evaluation Program) tool. Assuming that the Link/Site addresses of bridges in the STN inventory is correct, the BEP tool can automatically translate the Link/Site addresses of bridges in the STN inventory to the corresponding bridges in the Bridge Log. However, there are discrepancies between bridges in the Bridge Log and STN inventory as illustrated in Section 4.1. These discrepancies can be resolved using techniques illustrated in Section 4.4.

5.2 Construction Restrictions

Construction projects can cause temporary closures or restrictions on roadways. A construction project can occur on multiple roadways and a roadway can be affected by multiple construction projects at the same or different times. Each project can cause multiple closures or restrictions at various times. Each restriction occurs during a certain period of time thus the expected start and end times of the restriction period are required for evaluating whether the restriction applies during the 2-week period that the permit is effective. In reality, though, the expected end times are indeterminate at times. This causes somewhat of a problem for evaluating the restriction due to construction projects. Nonetheless, the following lists describe the essential data required for the evaluation of restrictions due to construction projects.

Project-id. This is identification for a construction project to act as a foreign key in the relational database.

Restrict-id. As stated earlier, each project can cause multiple closures or restrictions at various times. The Restrict-id is identification for each closure or restriction that is caused by a construction project.

Link-id. Link-ids represent roadways that are affected by a construction project.

WisDOT currently maintains the construction data in a hard-copy map and AutoCAD drawings. Construction closures and restrictions are plotted on a construction map using symbols and color-coding. WisDOT also maintains a Construction Contract Administration System that describes construction closures and detours using Route, RP and offset location referencing method. To build the construction restrictions database, the spatial association between roadway network and construction projects must be determined.

A construction project can occur on multiple roadways or links. To determine the links affected by a construction project on a unique route, one needs to know the RP addresses (RP, offsets, and route designations) of the starting and ending points of the project on that route.

Subsequently, the RP addresses are translated to Link/Site addresses. The links that lie on or between the two Link/Site addresses are the links that are affected by the construction project.

If a construction project affects multiple non-concurrent routes, then the project starting and ending points on each route must be identified. Ignoring any of these routes will cause errors in the database. Situations when a project occurs on multiple non-concurrent routes include projects at interchanges and projects that start on one route and end on another.

Start date and time. This is the expected (or scheduled) starting time of a restriction period. This is not necessarily the starting time of the construction project since a construction project may cause multiple restriction periods.

End date and time. This is the expected (or scheduled) ending time of a restriction period. At times, the expected ending time is unidentified or indeterminate. This can be resolved by using an arbitrary time that ensures that the restriction will be end by then. For example, one may assume that a restriction period lasts about 10 years if the ending time of the restriction period is unknown.

Weight limit or allowable vertical and horizontal clearances (if applicable). A construction project may cause temporary closures or height, or width, or weight constraints. If any of these applies, the corresponding constraint data are needed for the evaluation.

5.3 Non-standard Highway Restrictions

A non-standard highway has narrow lane and/or shoulder widths. This may cause horizontal restriction to an oversize vehicle. A non-standard highway is a permanent constraint. Thus no time data is needed. Similar to the construction restriction, a non-standard highway may occur on multiple roadways. Therefore, the RP addresses of the staring and ending points of the non-standard highway are required. The following list describes the data required for the evaluation of the non-standard highway restriction.

Non-standard highway-id. This is a dummy identification for a non-standard highway to act as a foreign key in the relational database.

Horizontal clearance. This is an allowable horizontal clearance for the highway. It can be the summation of lane and shoulder widths.

Link-id. Link-ids spatially associate non-standard highways with the roadway network. Link-ids can be determined from the RP addresses of the starting and ending points of each non-standard highway.

The only problem to populate the non-standard highway database is to determine the RP addresses of the starting and ending points of the non-standard highways. This could be accomplished by estimating the addresses from a map. Once the RP addresses are determined, they are translated to the Link/Site addresses and then the links associated with the non-standard highways can be determined.

5.4 Spring-thaw Restrictions

Spring-thaw decreases the maximum capacity of the pavement. Similar to construction and non-standard highway constraints, spring-thaw may affect on multiple roadways. Spring-thaw occurs during a certain period of time each year. Thus the estimated stating and ending time of the spring-thaw are needed. The following lists identify the data needed for the evaluation of the spring-thaw restriction.

Thaw-id. This is a dummy identification for a spring-thaw that acts as a foreign key in the relational database.

Link-id. Link-ids spatially associate the spring-thaw restrictions with the roadway network. Link-ids can be determined from the RP addresses of the starting and ending points of the spring-thaw on each route.

Starting date and time. This is the expected starting time of year of the spring-thaw.

Ending date and time. This is the expected ending time of year of the spring-thaw.

Weight limit. This is the maximum allowable weight of the pavement during the spring-thaw period.

The RP addresses of the starting and ending points of the spring-thaw effect on a route need to be determined in order to find the spatial association between the spring-thaw and roadway network. In addition to the RP addresses, the anticipated starting and ending times as well as the maximum allowable weight of the spring-thaw need to be identified.

5.5 Escort Restrictions

A vehicle with certain size and/or weight is required by some local jurisdictions to have an escort by highway patrol to go through certain roadways. The following lists show the data required for evaluating whether a vehicle is needed patrol escort to travel through a permit route.

Escort-id. This is a dummy identification that acts as a foreign key in the relational database.

Link-id. Link-ids spatially associate the escort restrictions with the roadway network. Link-ids can be determined from the RP addresses of the starting and ending points of the escort territory on each route.

Horizontal, vertical clearances and/or weight limit (if applicable). This is a restricted size and weight of vehicle defined by a local jurisdiction. A vehicle that is bigger or heavier than the restricted size or weight, respectively, is required an escort by a highway patrol.

Escort instruction. Escort instruction is a guideline or special conditions that must be conformed during the escort.

Similar to previous restrictions, the RP addresses of the starting and ending points of the escort territory on each route need to be identified. Then those RP addresses are converted to the Link/Site addresses. Subsequently, the link associated with the escort restriction can be determined from the Link/Site addresses. The remaining escort data including size and weight limit as well as the escort instruction are currently available.

If escort restrictions apply to a route over its entire length through a municipality or county then the location references for the escort restriction can be populated using the administrative data from STN Inventory (personal communication with Jonathan DuChateau, WisDOT, April 12, 2002). STN Inventory has the municipality and county attached to Links. This would be much easier than manually entering the start and end points of each roadway that passes through a territory. This would alter the data model slightly, but would also make data maintenance much easier because any change to the territory boundary can be automatically propagated to the restriction data. For example, if a city with a restriction annexes land that results in another highway to be within the city, the restriction database can be automatically updated using STN Inventory.

5.6 Special Event and Local Restrictions

Special restrictions include local restrictions on Milwaukee Express Way, Daily or Weekly Traffic restrictions and special restrictions due to parades or the Greenbay Packer games. The special event restrictions can be classified into 5 categories: temporary restriction, temporary closure, daily restriction, weekly restriction, and seasonal restriction. The categories are defined according to whether it is a restriction (restrict certain size and/or weight of vehicle) or closure, whether it has designated start and end times, and whether it has a weekly or daily cycle.

Since each type of the special events presents unique properties, different types of data are required for evaluating the restriction due to each special event. The following subsections list the data required for the evaluation of each type of the special restrictions.

5.6.1 Temporary Closures

Temporary closure is similar to temporary restriction with an exception that the roadway is completely closed instead of restricted to the certain size and/or weight of vehicle. The temporary closure and temporary restriction can be caused by the same special event such as parades or the Packer's games. The following lists identify the data that are needed for checking the restriction due to the temporary closure.

Event-id. This is a dummy identification that acts as a foreign key in the relational database.

Link-id. Link-ids spatially associate the special event restrictions with the roadway network. Link-ids can be determined from the RP addresses of the starting and ending points on each route.

Description. This is intended for additional information or conditions accompanied with the special event. This is actually optional. It is not used for the restriction analysis.

Start date and time. This is the expected starting time of year of the restriction (e.g. January 1, 2001 18.00).

End date and time. This is the expected ending time of year of the restriction.

The RP addresses of the starting and ending points on each route of the restrictions need to be identified. Then those RP addresses are converted to the Link/Site addresses. Subsequently, the links associated with the restrictions can be determined from the Link/Site addresses of the starting and ending points on each route. The remaining data including size and weight limits as well as the start and end times should not be too hard to determine.

5.6.1 Temporary Restrictions

A parade can cause temporary restriction, which restricts certain size and/or weight of a vehicle on certain roadways during certain period of time. The following lists identify the data that are needed for checking the restriction due to the temporary restriction.

Event-id. This is a dummy identification that acts as a foreign key in the relational database.

Link-id. Link-ids spatially associate the special event restrictions with the roadway network. Link-ids can be determined from the RP addresses of the starting and ending points on each route.

Description. This is intended for additional information or conditions accompanied with the special event. This is actually optional. It is not used for the restriction analysis.

Start date and time. This is the expected starting time of year of the restriction (e.g. January 1, 2001 18.00).

End date and time. This is the expected ending time of year of the restriction.

Horizontal, vertical clearances and/or weight limit (if applicable). This is a restricted size and weight of vehicle dictated by the special event.

The RP addresses of the starting and ending points on each route of the restrictions need to be identified. Then those RP addresses are converted to the Link/Site addresses. Subsequently, the links associated with the restrictions can be determined from the Link/Site addresses of the starting and ending points on each route. The remaining data including size and weight limits as well as the start and end times should not be too hard to determine.

5.6.2 Daily Restrictions

Daily restriction is typically caused by traffic regulations. For example, daily rush hour congestion may cause daily restriction. Vehicle with certain size and/or weight may not allow on certain roadways during certain time of day. This restriction may be effective every day or during the weekday only. The daily restriction is supposedly effective all year round. Thus no start and end times of the year are required. The following lists identify the data that are needed for checking the restriction due to the daily restriction.

Event-id. This is a dummy identification that acts as a foreign key in the relational database.

Link-id. Link-ids spatially associate the special event restrictions with the roadway network. Link-ids can be determined from the RP addresses of the starting and ending points on each route.

Description. This is intended for additional information or conditions accompanied with the special event. This is actually optional. It is not used for the restriction analysis.

Daily start time. This is the daily starting time of the restriction (e.g. 18.00).

Daily end time. This is the daily ending time of the restriction.

Mon-Fri only. This is basically a flag to indicate whether or not the restriction is effective during the weekday only. The value in this field can be either "Yes" or "No:"

Yes = Effective weekday only

No = Effective every day

Horizontal, vertical clearances and/or weight limit (if applicable). This is a restricted size and weight of vehicle dictated by the restriction.

The RP addresses of the starting and ending points on each route of the restrictions need to be identified. Then those RP addresses are converted to the Link/Site addresses. Subsequently, the links associated with the restrictions can be determined from the Link/Site addresses of the starting and ending points on each route. The remaining data including size and weight limits as well as the start and end times should not be too hard to determine.

5.6.3 Weekly Restrictions

Weekly restriction is similar to daily restriction with an exception that the restriction is effective weekly instead of daily. It can be caused by the traffic regulations such as the restriction on Milwaukee Express Way. Vehicle with certain size and/or weight may not allow on certain roadways during certain time of week. The weekly restriction is supposedly effective all year round. Thus no start and end times of the year are required. The following lists identify the data needed for checking the restriction due to the weekly restriction.

Event-id. This is a dummy identification to act as a foreign key in the relational database.

Link-id. Link-ids spatially associate the special event restrictions with the roadway network. Link-ids can be determined from the RP addresses of the starting and ending points on each route.

Description. This is intended for additional information or conditions accompanied with the special event. This is actually optional. It is not used for the restriction analysis.

Start weekday and Weekly start time. The Start weekday indicates the day of week (e.g. Sunday, Monday, etc.) while the Weekly start time (based on 24-hours clock system) indicates the time on that day the restriction starts to be effective.

End weekday and Weekly end time. The End weekday indicates the day of week while the Weekly end time indicates the time on that day the restriction ends.

Horizontal, vertical clearances and/or weight limit (if applicable). This is a restricted size and weight of vehicle dictated by the restriction.

The RP addresses of the starting and ending points on each route of the restrictions need to be identified. Then those RP addresses are converted to the Link/Site addresses. Subsequently, the links associated with the restrictions can be determined from the Link/Site addresses of the starting and ending points on each route. The remaining data including size and weight limits as well as the start and end times should not be too hard to determine.

5.6.4 Seasonal Restrictions

This is probably the trickiest restriction to model. An example of the seasonal restriction is such the restriction that begins Friday afternoon and ends Sunday afternoon during the summer tourist season between Memorial Day and Labor Day. Seasonal restriction has two starting and ending times: 1) season starting and ending times, and 2) weekly starting and ending. According to the example, Memorial Day and Labor Day are season starting and ending times, respectively. Meanwhile, Friday afternoon and Sunday afternoon are weekly starting and ending times, respectively. The following lists identify the data needed for checking the restriction due to the seasonal restriction.

Event-id. This is a dummy identification that acts as a foreign key in the relational database.

Link-id. Link-ids spatially associate the special event restrictions with the roadway network. Link-ids can be determined from the RP addresses of the starting and ending points on each route.

Description. This is intended for additional information or conditions accompanied with the special event. This is actually optional. It is not used for the restriction analysis.

Season start date. The "Season start date" indicates the time of year (e.g. January 1, 2001) that the season starts.

Season end date. This "Season end date" indicates the time of year that the season ends.

Start weekday and Weekly start time. The "Start weekday" indicates the day of week (e.g. Sunday, Monday, etc.) while the "Weekly start time" (based on 24-hours clock system) indicates the time on that day the restriction starts to be effective.

End weekday and Weekly end time. The "End weekday" indicates the day of week while the "Weekly end time" indicates the time on that day the restriction ends.

Horizontal, vertical clearances and/or weight limit (if applicable). This is a restricted size and weight of vehicle dictated by the restriction.

The RP addresses of the starting and ending points on each route of the restrictions need to be identified. Then those RP addresses are converted to the Link/Site addresses. Subsequently, the links associated with the restrictions can be determined from the Link/Site addresses of the starting and ending points on each route. The remaining data including size and weight limits as well as the start and end times should not be too hard to determine.

4 IMPLEMENTATION

The experienced gained from this project clearly illustrate that Wisconsin DOT's LCM data model can support routing and route checking for OS/OW permitting. The link and offset referencing system supports the integration and management of roadway characteristics and routing restrictions. The link/site network provides the topological model that is essential for generating routes.

Implementation of the OS/OW Vehicle Routing System requires the following tasks. These tasks are associated with building software system and data integration interfaces, expanding the data model and routing algorithm to include additional restriction types, preparing data sets.

1) ***Build software interface to OPUS/OOPPS.*** This interface will pass customer, vehicle, and travel information from OPUS/OOPPS to the OS/OW Vehicle Routing System application.
2) ***Revise data model to comply with Wisconsin DOT's naming convention.***
3) ***Design and build interface for designating Origin/Destination.*** Alternatives for accomplishing this task include using a cartographic map and point-and-click to designate origin and destination; drop down menus that lists access points by road name, county, township or district; and using ON/AT referencing system such as used for Wisconsin local roads.
4) U***se the data cleaning tools to build bridge restriction data set.*** Tools such as BEP and Bridge View tools must be used statewide to identify and resolve discrepancies between existing data sources of bridge locations.
5) ***Create new "relax" restriction type associated with links that become effective based upon commodity and permit type.*** Certain vehicles have "relaxed" restriction on routes. The data model and routing algorithm should be updated to accommodate this type of restriction.
6) ***Include pavement rating as a restriction type.*** The data model and routing algorithm should be expanded to consider pavement rating when evaluating routes. The current system does not include pavement analysis.
7) ***Build interfaces to existing databases for restrictions.*** Interfaces are required for adding, updating and deleting records in the OS/OW Routing and Restriction Database. Interface may also be developed to seamlessly update the restriction database by querying other existing datasets. Existing datasets of restrictions include the following: construction project database, spring-thaw database, defines non-standard highways; define local restrictions; define escort restrictions and instructions.

During the process of designing and implementing the OS/OW Vehicle Routing System, the Research Team identified a number of issues that must addressed but are beyond the scope of this application development project. These issues include the following:

1) ***Improve cartographic representation in maps to more closely resemble the state highway map.*** Improved cartographic maps (larger scale) are needed to optimally represent a route and accurately designate origin and destinations.
2) ***Include local roads network.*** Local roads need to be incorporated to the STN, in order to thoroughly verify all restrictions from origin and destination.

3) Revise business processes so the LCM and STN updates are made available to OS/OW Vehicle Routing System in near real-time. Current LCM and STN data are vital for the successful operation of the routing and restriction checking.

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