University Transportation Research Center - Region 2

Final Report

Development of a Comprehensive Inventory Management System for Underground Fiber Optic Conduits

Performing Organization: New Jersey Institute of Technology

March 2013

Sponsor:
University Transportation Research Center - Region 2

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

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16. Abstract

Major State Departments of Transportation operate and maintain networks of thousands of miles of conduits, many carrying fiber optic cables that are vital to State communication systems. These conduits are located alongside or across highways and frequently must be located and marked to avoid damage from digging or boring resulting from construction.

The existing inventory system often consists merely of sections of pipelines of varying length with differing lengths and sometimes unknown or changing diameters and materials. In order to facilitate the location of fiber optic facilities by operations personnel and enable access to junction boxes and conduits, a computerized connectivity-based inventory system of all external (pipes, junction boxes) and internal assets (conduits, cables) was developed. In a first phase, the system enabled the transition from a flat incomplete and inaccurate system of facility identification to a network model of fiber optic segments and nodes (junction boxes). In this work, a comprehensive hierarchical system of facility cataloguing was achieved through an expansion of the system to include multiple inner layers within pipes and junction boxes, such as Conduits and Cables. This enabled the definition of a Routing entity, an essential component of a comprehensive fiber optic connectivity-based system. Key to the system design is the definition of the multi-layered hierarchical relationship between various levels of facility definition. The ability to "drill-down" from an external layer to an inner component and to establish multi-directional facility contiguity enables the progressive improvement of data quality and the establishment of a reliable connectivity model between facilities. This extended prototype enables the successful future transition from a system based on section records to a more connectivity-based hierarchical asset management model of fiber optic underground facilities, with significant savings in operational costs and reliability of the field investigative work, and the support of improved maintenance management and capacity/capital planning.

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TABLE OF CONTENTS **Page**

LIST OF TABLES **Page**

LIST OF FIGURES **Page**

1. BACKGROUND

The New Jersey Department of Transportation (NJDOT) operates and maintains a network of thousands of miles of conduits (Intelligent Transportation Systems (ITS) infrastructure), approximately close to 600 miles of it carries fiber optic cables that are vital to the State of New Jersey communication system. These conduits have to be located and marked prior to construction activities to avoid potential damages.

In a previous project (1), the development of a computerized database of junction boxes and segments was undertaken as a first step towards a complete inventory management system. The existing inventory of the ITS consists of sections of conduits of variable lengths, diameters and materials, often crossing several junction boxes which are key access and segment connection nodes and are not included in the existing computerized inventory system. The inclusion of the junction box and segment detail data, provided a first level of asset connectivity relationship in the inventory system. The current project expands the connectivity capability to the inner layers of the segments and junction boxes, to include conduits and cables.

Much of the problem of developing an inventory system for intelligent transportation system assets lies in the proper location of various asset categories, particularly the definition of the start nodes and end nodes of various pipe segments (links), in the absence of a junction box inventory, with detailed and accurate as-built drawings enabling the identification of the relationships between links and nodes.

2. PROJECT OBJECTIVES

The overall objective of this project (2) was to start the development of the system with the development of a computerized inventory of all ITS “external” Facilities, including conduits, junction boxes, cameras, connections, etc., with an initial focus on the junction box facilities currently missing from the inventory system. The existing system consists of a computerized table of conduit sections, with various lengths, without reference to sometimes changing materials and unknown intermediate numbers, types, and locations of junction boxes. It was clear that the accurate location of conduits in the medium and long-term can be best undertaken with a cross-referenced segment and junction box inventory. The junction box inventory was created, with a design that enabled the gradual creation of the segment and junction box detailed inventory in the event of absence or unavailability of detailed drawings.

Building on the initial prototype, the objectives of the current project are to:

1. Examine and understand the full data requirements of all assets in the network of facilities in the fiber optic network of a State transportation system such as NJDOT or NYDOT, including all segments and node types, as well as the stretches of cables housed within them or routed through them.
2. Develop a comprehensive data model that allows both immediate access to all facilities in a given location, as well as other facilities housed within them (in the case of

cables), and connected to them (segments, junction boxes, etc.). This would enable the coverage of both external and internal assets.

3. Design a system flow that enables both hierarchical drill-down from a section to its children segments and nodes, as well as connectivity (navigation from a facility to its neighboring or contiguous facilities, and the cables running through them).

4. Expand the development of the prototype system to include the capabilities above, thus making the system a total navigation system for all inventory of facilities within the network.

The initial prototype established a baseline of all key external facilities such as pipe segments and junction boxes was established. However, due to the possible lack of detailed drawings establishing the relationships between various segments and junction boxes, a new Entity, called Extremity, was created to allow for a temporary “repository” of a segment to junction box connection. The Extremity recognition and validation would take place during the survey of junction boxes, which would include assessing and taking photographs of the inner surface of a junction box.

This baseline made it possible to tackle in this second phase of development the inner layers of inventory elements consisting of conduits within pipes and cables within conduits and junction boxes. This expansion of the system inventory elements helps establish a hierarchical multi-layered inventory system, an essential ingredient of comprehensive connectivity.

The ultimate goal of the project is to develop the information structure required to enable the coverage of and easy navigation between all facilities (external and internal) managed by ITS. The first phase consisted of a pilot system focused on external facilities and the creation of a Node entity which includes the junction boxes (JB), an essential cross-segment entity that was not represented in the inventory system, A proper cataloguing of the JB’s is critical to an improvement in the completeness and quality of the pipe segment records, as each segment could now be defined by its starting and ending JB nodes. In order to preserve data integrity, the original section-level data was integrated in the system as in the previous prototype, in order to enable the gradual transition of the system towards a comprehensive inventory database management system of all ITS facilities. Key criteria for success of this study include:

1- TECHNOLOGY SELECTION: the ability to develop a system that can be accessed by multiple users, and maintained by ITS and other State DOT departments.

2- CONSERVATION AND IMPROVEMENT OF INVENTORY KNOWLEDGE: The ability to create a new set of data related to junction boxes without losing the prior information related to section-level data was essential to the conservation and gradual improvement of inventory knowledge. The junction box data helps improve gradually the conduit-level information, by facilitating the creation of segment-level (JB to JB) data, thus improving the accuracy of conduit information. By extension, the creation of the inner layers of inventory inside pipe segments helps complete the inventory of all facilities, including conduits (ducts) within pipes and cables within conduits and junction boxes.

3- NETWORK INVENTORY CONNECTIVITY AND COMPLETENESS: the ability to improve the information base regarding the location and completeness of the entire network and its facilities, both as a concerted database effort, and as a result of future field investigations. For example, the inventory of all pipe extremities within each junction box and their association with segments and sections, allows the definition of a real network model. Moreover, the ability to "drill-down" and "drill-up" between the section and the segment levels can help improve data accuracy and completeness at both levels, and enable the navigation across the network both from the outside in (using facility hierarchical relationships), and across the facilities in multiple directions, using contiguity data. Also the establishment of cable entities (cable stretches within conduits), and routings (multiple cable stretches in a sequence of conduits and junction boxes), enables the management of the cable assets in terms of location and possible future maintenance and repair needs.

3. ITS Facilities Inventory Version 1 Design: Entity Relationships

The previous Version 1 of the inventory system of ITS facilities (1) enabled the creation of a multi-user system covering section, segment and junction box/node entities, which are displayed in Diagram 1:

1- Current Sections remain the highest level entity in conduit description, and the existing data is ported to that entity.
2- The Entity (NODE) remains representative of a category of assets, with values of Junction Box (JB), Camera, Controller, etc.
3- The Entity (Segment) now represents a Node to Node conduit pipe containing one or more fiber optic cable stretches.
4- A section therefore "contains" or is connected to many Nodes (mostly JB), and thus a hierarchical relationship exists between sections and its related "children" Nodes.
5- A section also has many children segments (Node to Node), and a hierarchy of section to segment also exists (1:n) relationship.
6- As described above, the Entity "Extremity" was created to ascertain the relationship of segments to Nodes after a detailed field investigation. A node contains multiple extremities of segments of pipes (1: n relationship), which can be characterized once a junction box has been inventoried, and its interior section surveyed.
7- A Node is therefore potentially connected to many extremities and to many segments, but a Segment is connected to 2 Nodes (Start and end Nodes).

In summary:

A section contains one or more segments
A section contains one or more nodes, typically Junction Boxes
A node contains one or more extremities
A segment is connected to two nodes
A node is connected to one or more segments
A junction box is a type of node

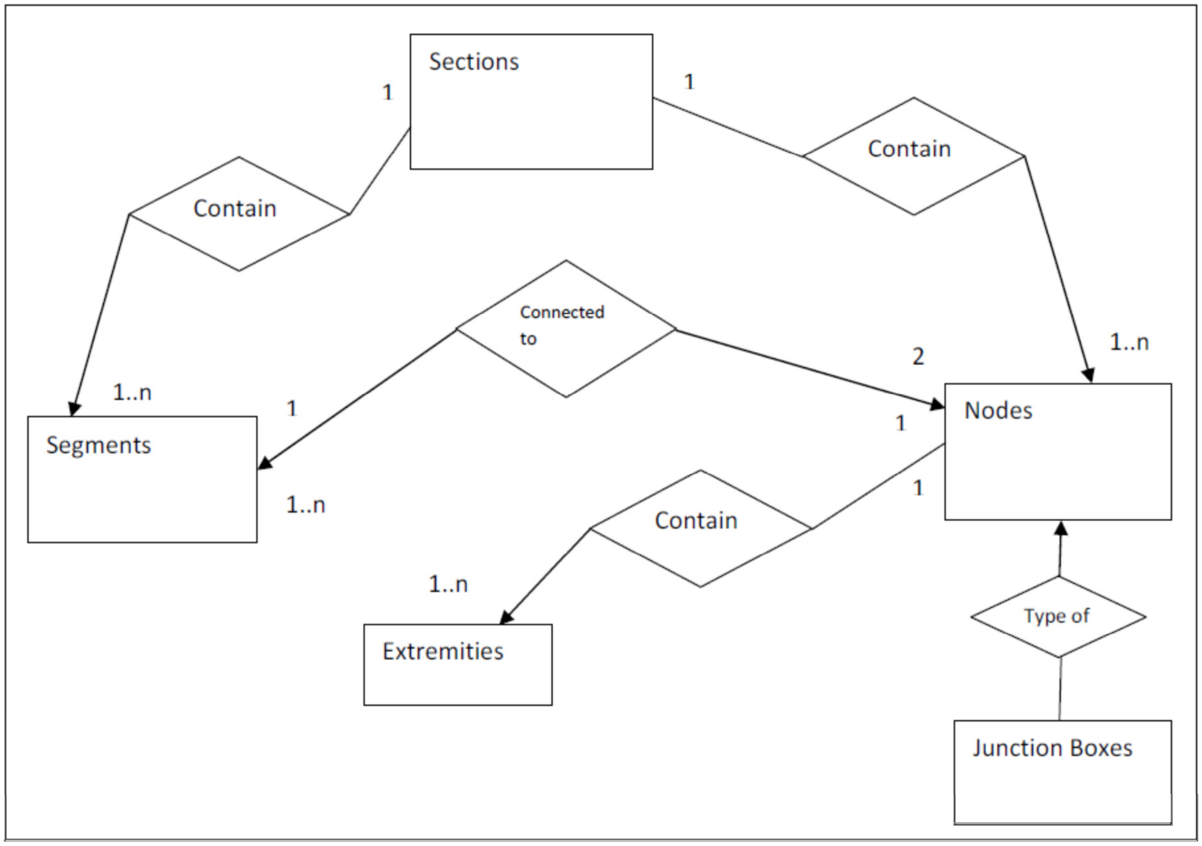

Figure 1: **Entity – Relationship Diagram (Version 1)**

4. ITS Facilities Inventory Development Plan and Data Structures

In order to achieve the objectives stated above, a new database design, that emphasizes completeness and connectivity, was devised and implemented for a large sample of existing and demo-level junction box and related pipe segment data collected during prior field investigations. Subsequently, the inner layers of conduits and cables were "connected" to the external facilities to provide for a full functionality related to multi-level inventory data navigation.

The new ITS Facilities inventory should make it possible to manage the system as a network of nodes and links, with all specifications for various nodes and links, and with relationships to the inner layers of cables within segments and junction boxes.

This connectivity- based comprehensive network inventory system, includes new entities and relationships. The new and expanded ITS Facilities inventory design makes it possible to manage the system as a multi-level hierarchical network of nodes and links and their inner conduits and cables, with detailed possible specifications for various nodes and links.

The expanded system design consists of the following entities and relationships, which are displayed in Diagram 2:

1- Current sections remain the highest level entity in conduit description, and the existing data is ported to that entity.
2- A new entity (node) was added in Version 1, with type values of junction box (JB), camera, controller, etc.
3- A new entity (segment) was created in Version 1, which represents a node to node conduit pipe containing one or more fiber optic cable stretches.
4- A section therefore "contains" or incorporates many nodes (mostly JB), and thus a hierarchical relationship exists between sections and its related "children" nodes.
5- A section also has many children segments (node to node), and a hierarchy of section to segment also exists (1:n) relationship.
6- A node contains multiple extremities of segments of pipes (1: n relationship), which can be characterized once a junction box has been inventoried, and its interior section surveyed. The entity "Extremity" is essential to the gradual enabling of an accurate connectivity-based system. These are verified while surveying the interior of a JB, until such time as the matching of extremities with segments can be ascertained.
7- A node therefore potentially incorporates many extremities and is connected to many segments, but a segment is connected to 2 nodes (START and END nodes).
8- A Segment consists of many conduits (1: n relationship), with n typically equal to 1,2 or 4. Each conduit contains multiple cables (1: n relationship). Also each Node/Junction Box (item 2 above) can contain multiple cables.
9- Routings are defined as stretches of single or multiple cables within a sequence of conduits and nodes.

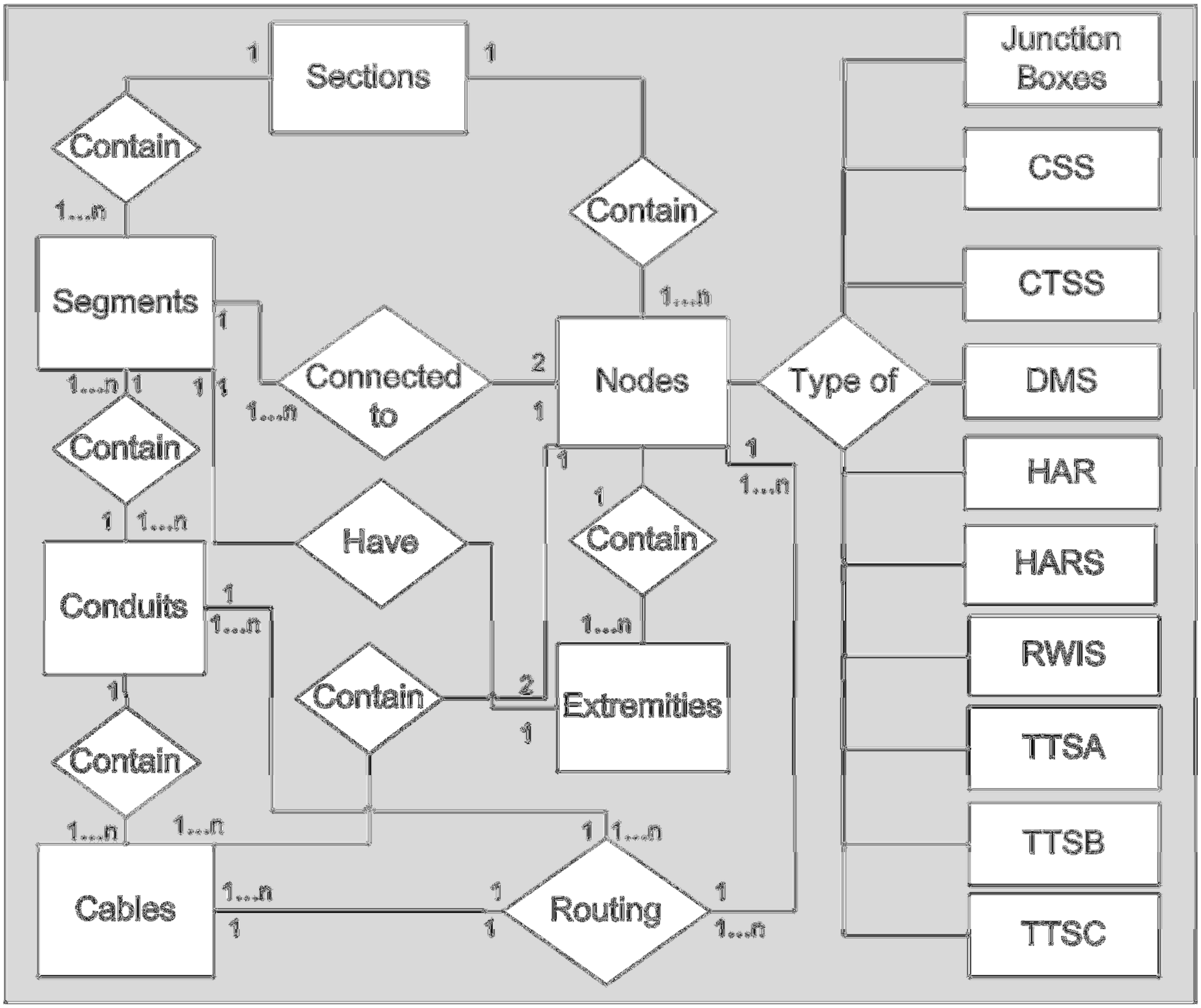

Figure 2. Entity – Relationship Diagram (Expanded Version)

In order to enable the creation of the above design, the development plan for this project focused on the integration of the inner layers (conduits, cables, routings) was devised as follows:

1- Create the Conduit Layer, to represent the inner conduits that are children to the individual Segments.
2- Create the Parent to Child Relationship between Segments and Conduits.
3- Develop a Cable Layer, with specified markings within Conduits or Nodes.
4- Define Relationships between Conduits and Cables and Nodes and Cables
5- Define a Routing, as a Path, or stretch of cable within a sequence of conduits and Nodes.

In summary, new inventory layers within Segments and Nodes were defined to accommodate the cables, their locations, and their routing and connectivity across Segments and nodes. To that end, Segments were defined as parents of a new entity (layer), called “Conduits”. Conduits in turn are defined as parents of (contain) a new entity, the lowest inventory layer called “Cables”. Also, Nodes (Junction Boxes) contain or are parents of Cables. This in turn enables the definition of a Routing as a sequence of Cables, which are children of Conduits or Nodes.

In order to enable this development plan, new data tables, in addition to the Tables created in the previous version as well as system lookup tables, were created as follows:

Conduits	
Conduit_ID	Varchar
Start_node	Varchar
End_node	Varchar
Parent_segment	Varchar
Conduit_diameter	Number
Conduit_length	Number
Conduit_material	Varchar
Install_Date	Date
Color	Varchar
Conduit_type	Varchar
Comments	Varchar
Created_by	Varchar
Edited_by	Varchar

Table 1: Conduit Data Structure

Cables	
Cable_ID	Varchar
Start_node	Varchar
End_node	Varchar
Parent_conduit	Varchar
Cable_diameter	Number
Cable_length	Number
Cable_material	Varchar
Install_Date	Date
Color	Varchar
Cable_type	Varchar
Manufacturer	Varchar
Number_of_fibers	Number
System	Varchar
Subsystem	Varchar
Comments	Varchar
Created_by	Varchar
Edited_by	Varchar

Table 2: Cable Data Structure

Routing	
Routing_ID	Varchar
Cable_ID	Varchar
Conduit_ID	Varchar
Node_ID	Varchar
Intersection_type	Varchar
Intersection_length	Number
Multi_Cable	Yes/No
Install_Date	Date
System	Varchar
Subsystem	Varchar
Comments	Varchar
Created_by	Varchar
Edited_by	Varchar

Table 3: Routing Data Structure

The main design upgrades in the system can be summarized as follows:

1. Addition of a conduits layer as child to the segments layer. A segment can have several conduits running inside it. Each of these conduits contains one or more cables.
2. Addition of a cables layer as a child to the conduits layer, and/or the Nodes layer. A cable usually passes through several conduits and nodes between start and end points. The path of a cable is known as a routing.

3. A routing table has been created that records the conduits and nodes that a particular cable physically passes through.
4. Node types other than junction boxes will be expanded. Some of these node types are Camera Surveillance System (CSS), Computerized Traffic Signal System Device (CTSS), Dynamic Message Sign (DMS), Highway Advisory Radio Antenna(HAR), Highway Advisory Radio Sign (HARS), Roadway Weather Information System (RWIS), and different types of Travel Time System Sensors (TTSA, TTSB and TTSC).

5. ITS Facilities Inventory System Architecture and Functionality

The system Architecture is a distributed multi-user system with a graphical user interface, and a MySQL server-based database, which can be migrated to MS SQL

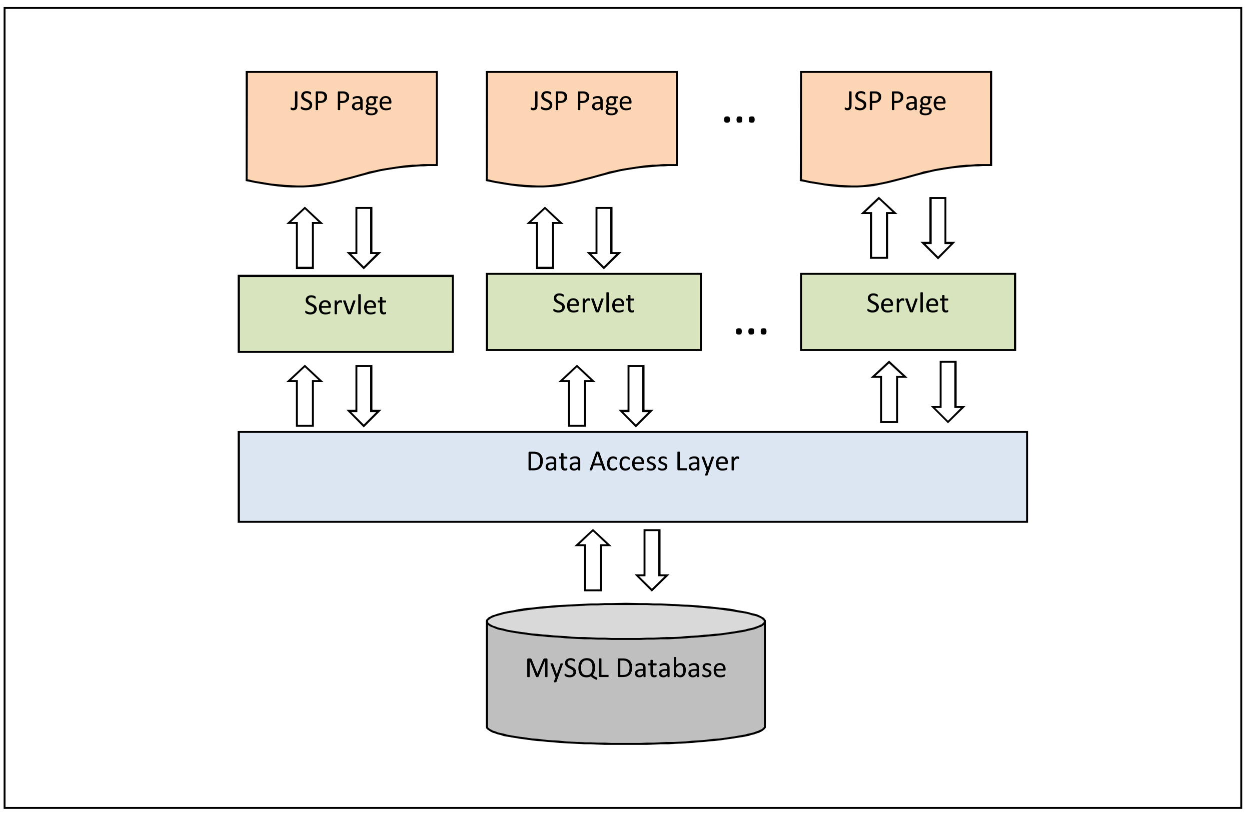

Figure 3. System Architecture Diagram

The system is a web-based application where the front end is designed as a collection of HTML/JSP pages. These pages submit requests to a collection of servlets which are Java programs designed to handle the functional logic of the system. These servlets interact through the MySql database through a Data Access Layer which is a Java class with database querying methods. The advantage of this three-tier design is twofold. Firstly, since only the Data Access Layer class interacts with the database, it is impossible for another program to make unintended changes to the database. Secondly, since all the database-related code is only in the Data Access Layer class, a migration of the system from MySQL to another database like MS Sql Server or Oracle will require the modification of just this one file.

The advantage of designing a web-based interface is that no additional installation is needed on the client machines. The users can access the system via a web browser and only the database server and the web server has to be maintained by the system administrator.

The system functionality can be described by the following sequence of pages/screens:

The homepage: This page appears after a successful login and contains the main menu to manage sections, segments, nodes, junction boxes, extremities, conduits, cables, routings, and also links to the Users, Help and Logout pages.

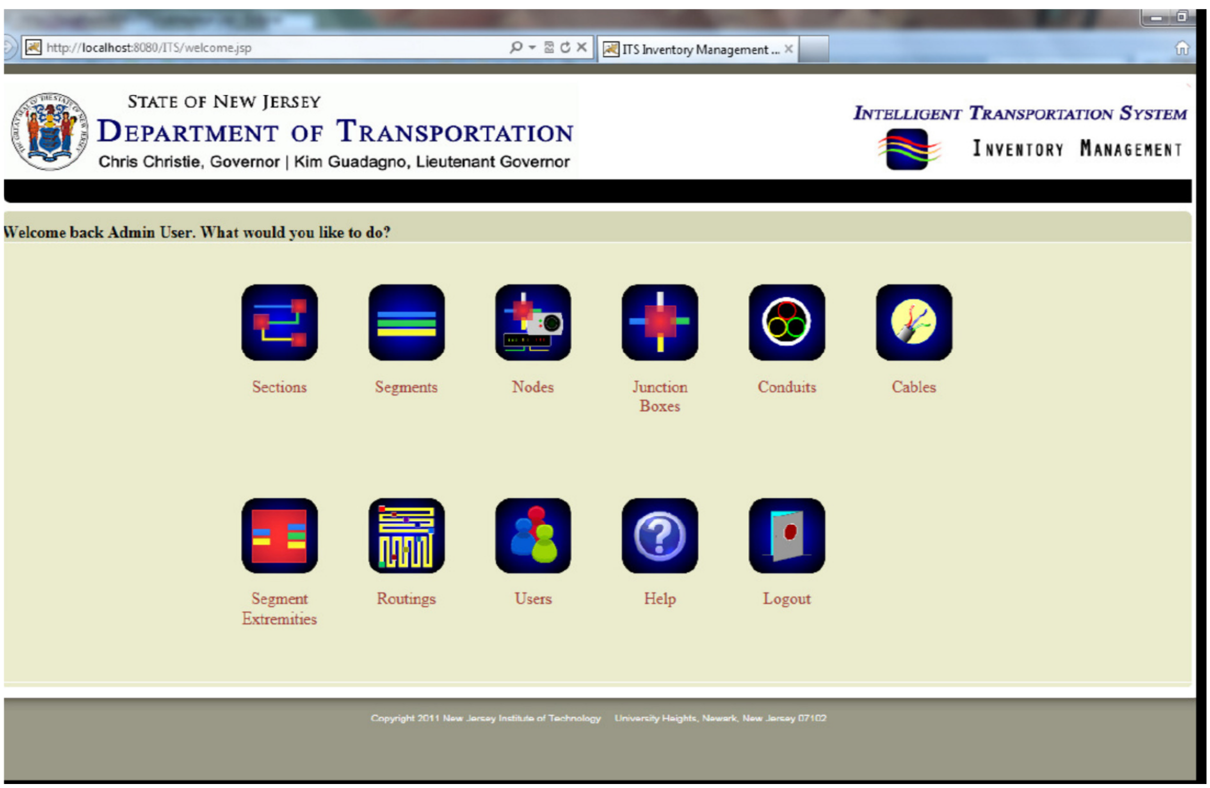

Figure 4. Homepage

The manage segments page: This page contains the menu for the different segment-related activities.

Figure 5. Manage Segments Page

The segment detail page: This page has all the details pertaining to a segment and also a list of nodes that are connected to that segment. This list can be sorted on any column and any item can be clicked to open the detailed view for that node.

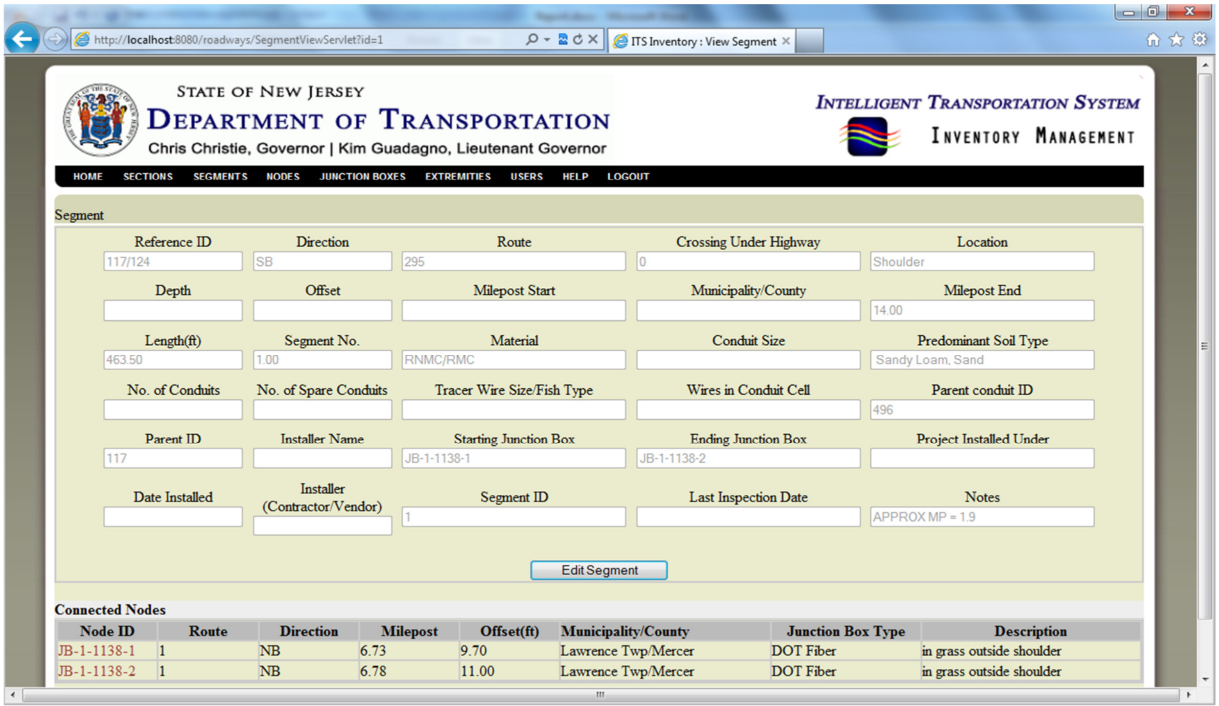

Figure 6. Segment Detail Page

The manage nodes page: This page contains the menu for the different node-related activities:

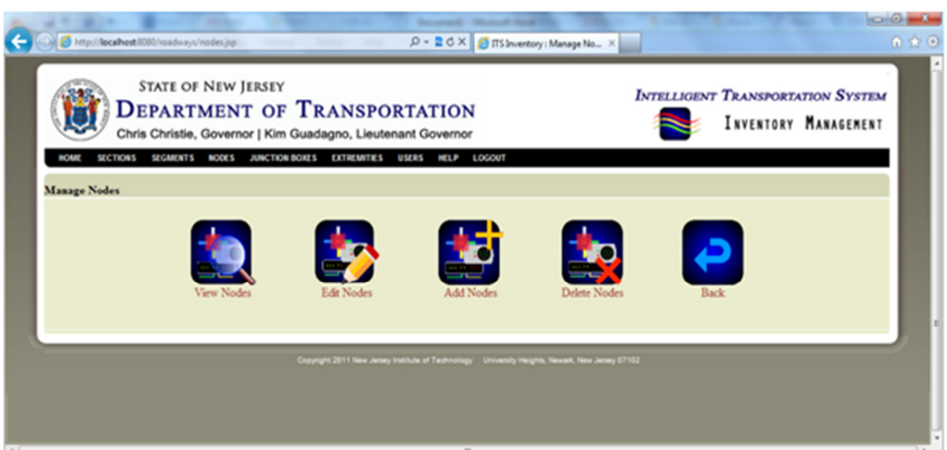

Figure 7. Manage Nodes Page

The manage junction boxes page: This page contains the menu for the different junction box-related activities.

Figure 8. Manage Junction Boxes Page

The view junction boxes page: This page allows the user to search for a junction box. The result is returned in the form of a table that can be sorted on any of the columns, and clicking on a Node ID in the list opens the detailed view for that junction box.

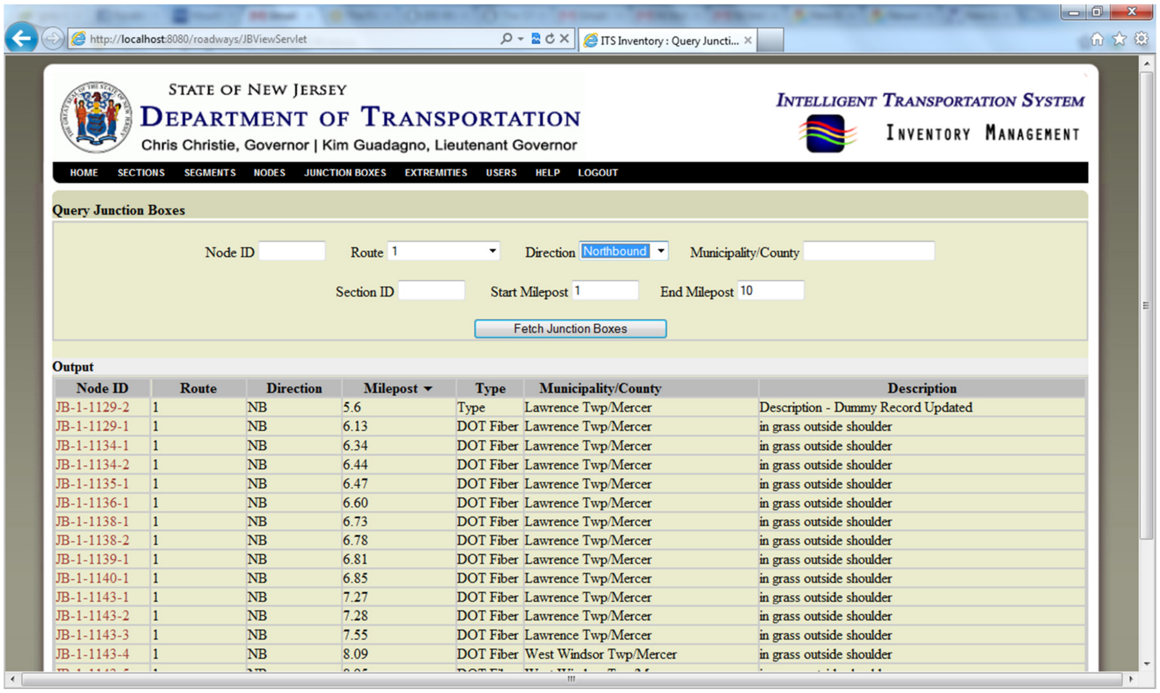

Figure 9. View Junction Boxes Page

The junction box detail page: This page has all the details pertaining to a junction box and also a list of nodes that are connected to that junction box (via a segment) in line with the connectivity focus of the system. This list can be sorted on any column and any item can be clicked to open the detailed view for that node.

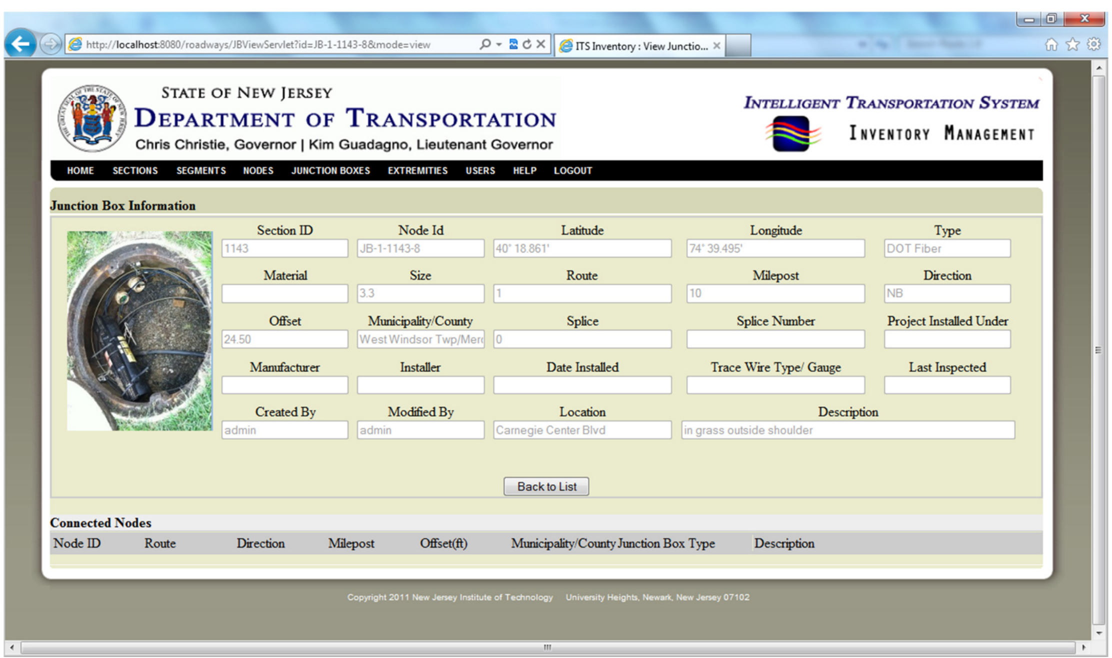

Figure 10. Junction Box Detail Page

The Add new junction box page: this page lets the user create a new junction box record. Once the route, milepost and direction are entered, the page refreshes and Section ID and municipality/county fields are autofilled.

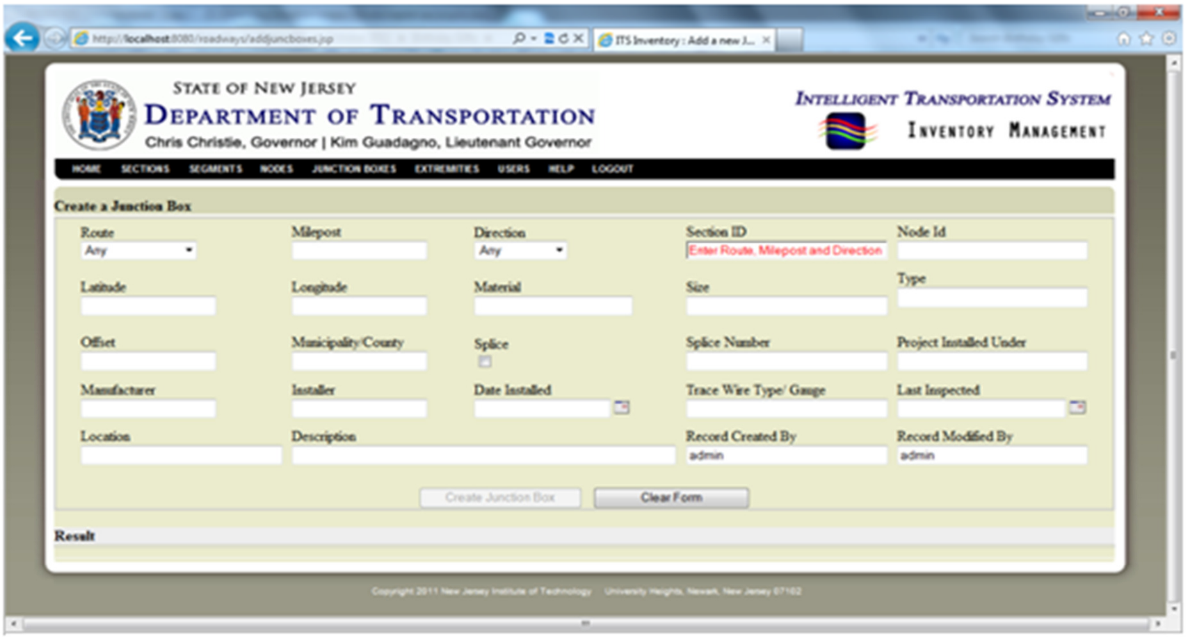

Figure 11. Add New Junction Box Page

The Add new junction box page (after calculating section#, county/municipality from database) is shown:

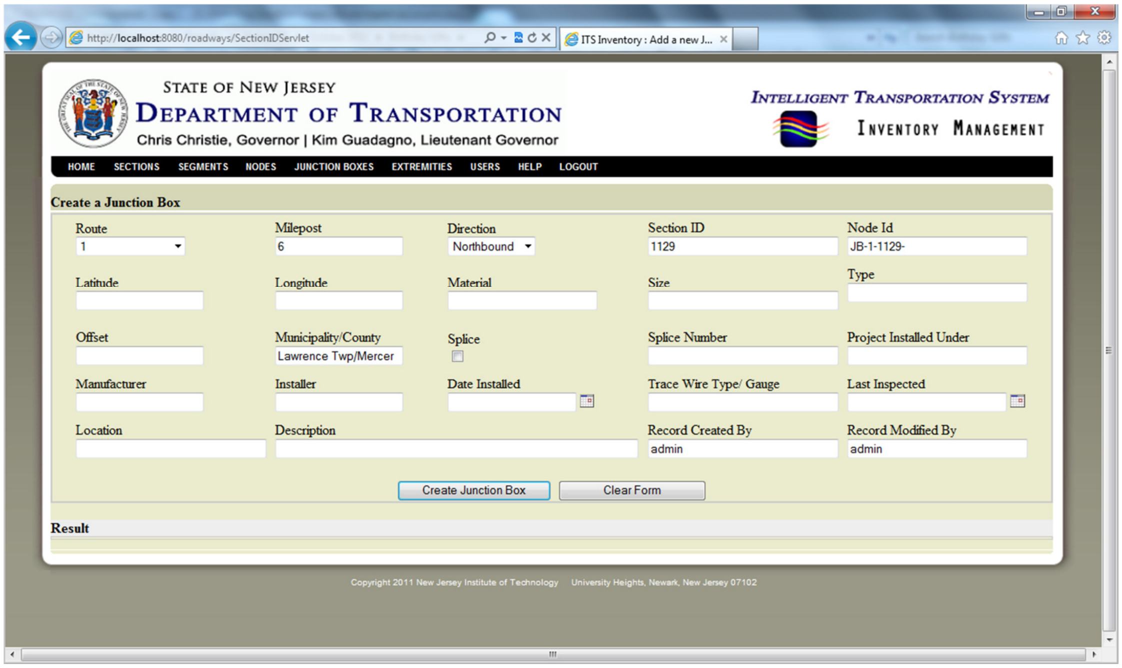

Figure 11a. Add New Junction Box Page

The manage extremities page: this page contains the menu for the different extremity-related activities.

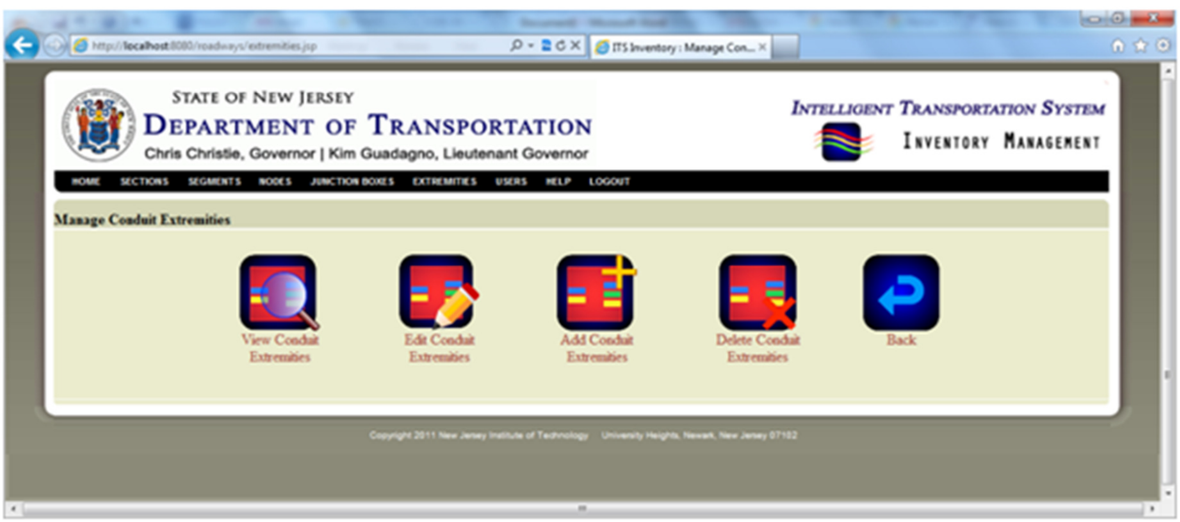

Figure 12. Manage Extremities Page

The Create Conduit page for a parent Segment ID will resemble the one below.

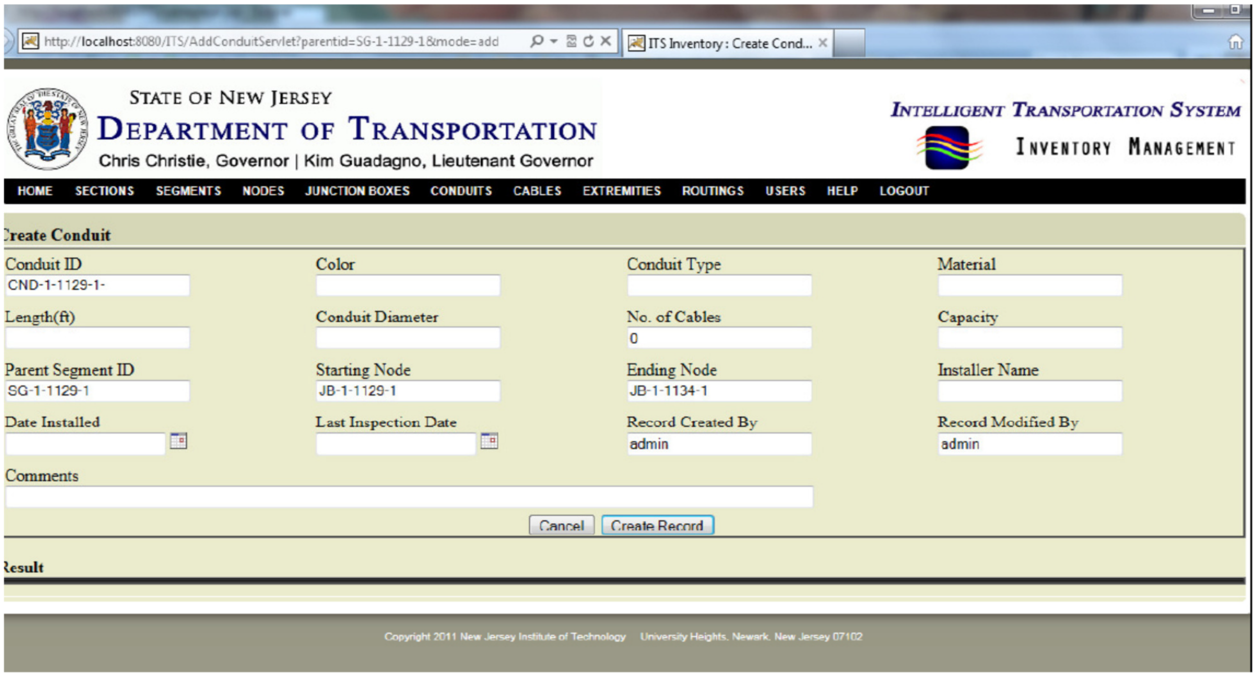

Figure 13. Create Conduit Page

The Add Cable Button is available within the "View Conduit Detail" page for a direct capability to add a Cable to the specified Conduit ID as in below.

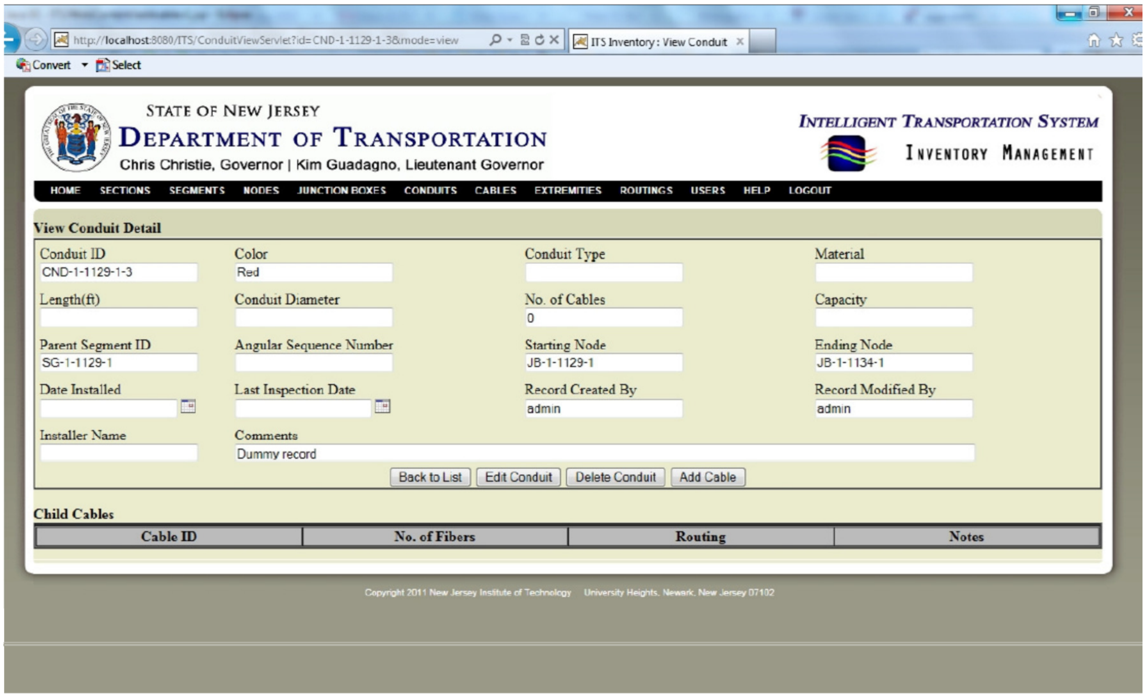

Figure 14. Add Cable Button within View Conduit Detail Page

The Add Cable Button is available within the "Junction Box Information" page for a direct capability to add a Cable to the Junction Box ID of interest as in below.

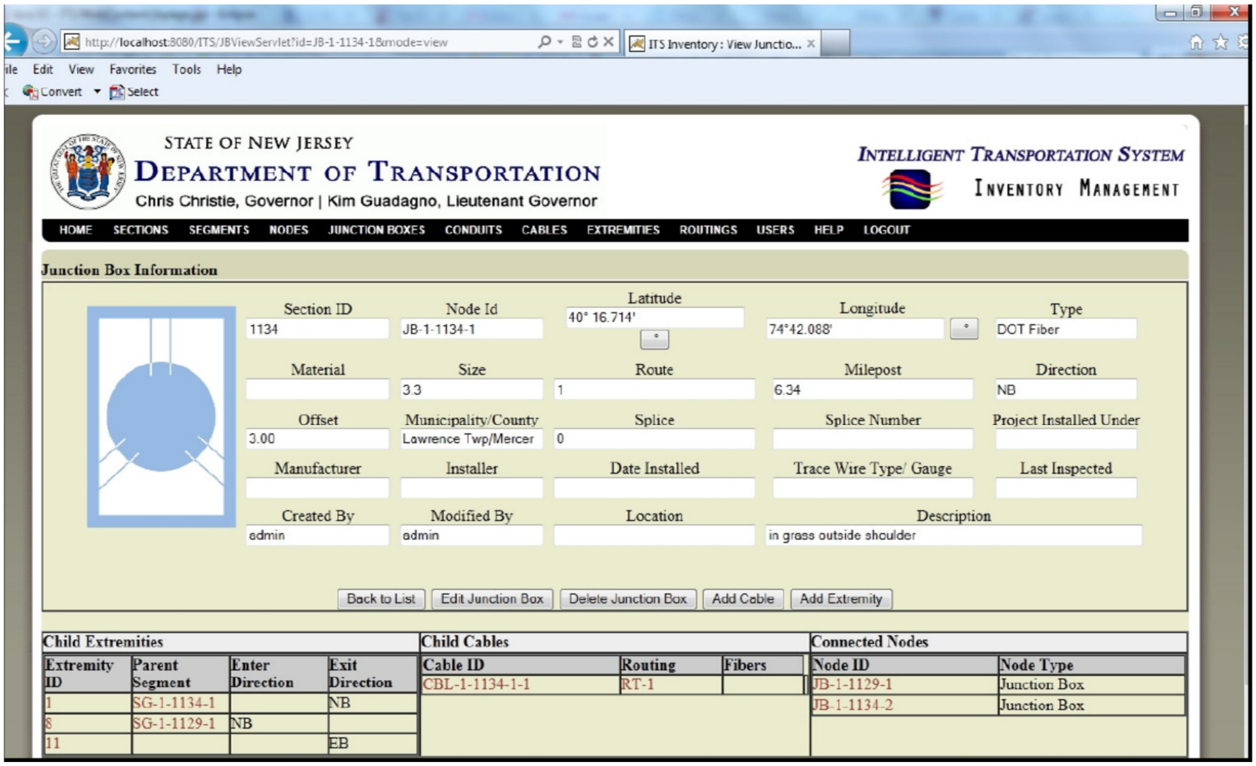

Figure 15. Add Cable Button within Junction Box Information Page

The Entity Routings is managed (Add, View, Edit, Delete) in the Page below:

Figure 16. Manage Routings Page

The Add Routing Page allows to create a routing based on a starting cable:

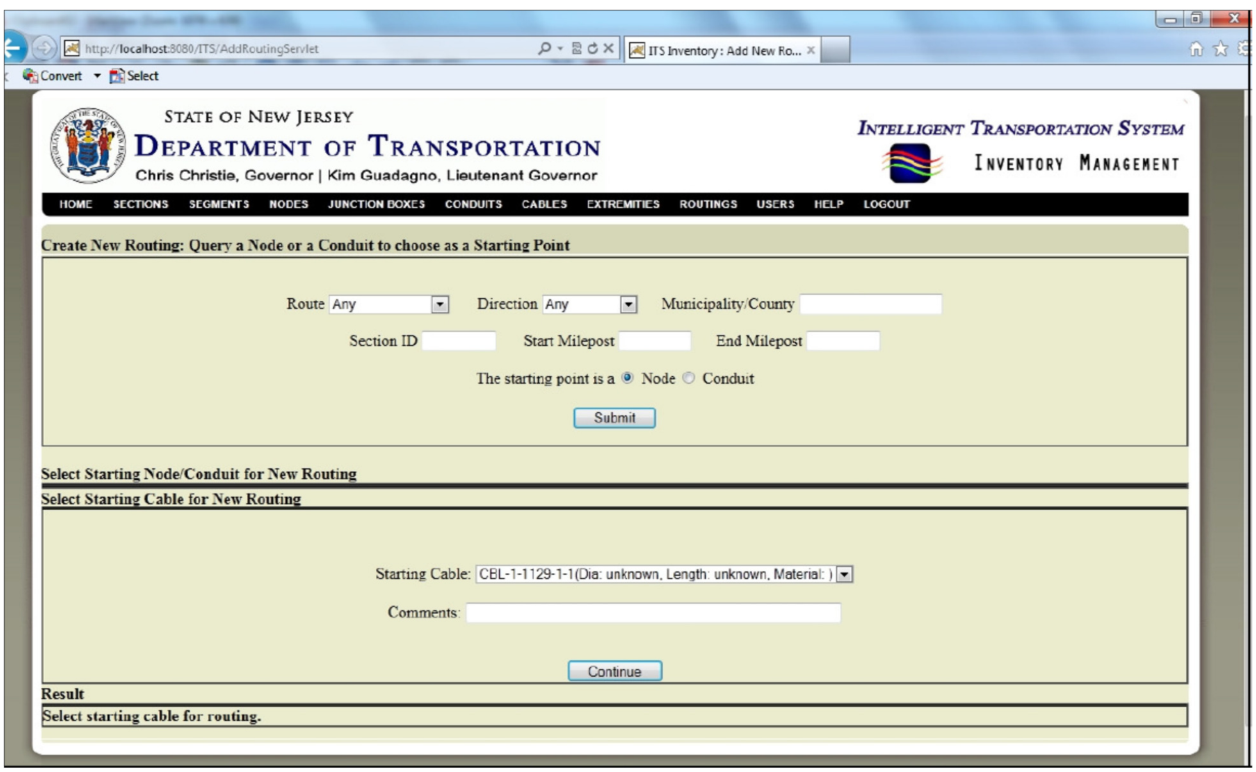

Figure 17. Create New Routing Page

The ability to Add a cable to a Routing or Remove a Cable is managed via a dedicated pop-up page within the Edit Routing Page. The Removal of a cable is managed by a Button next to any Constituent Cable within a Routing:

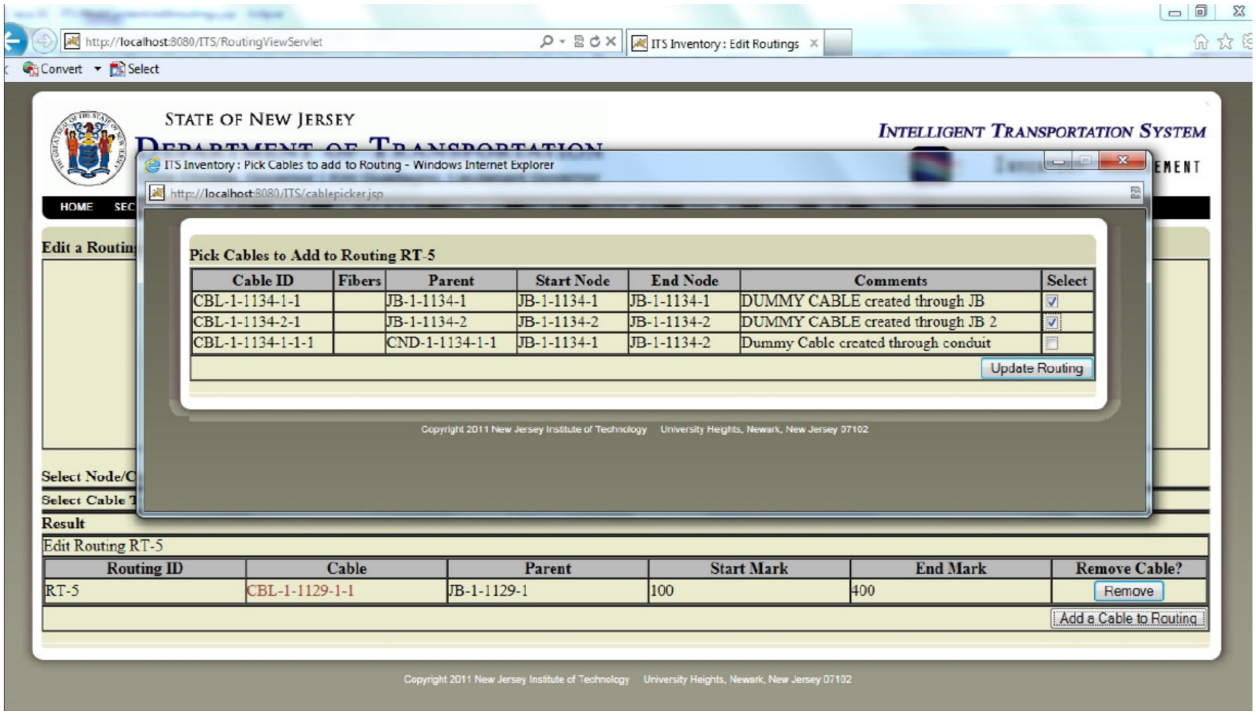

Figure 18. Add Cable to a Routing Page

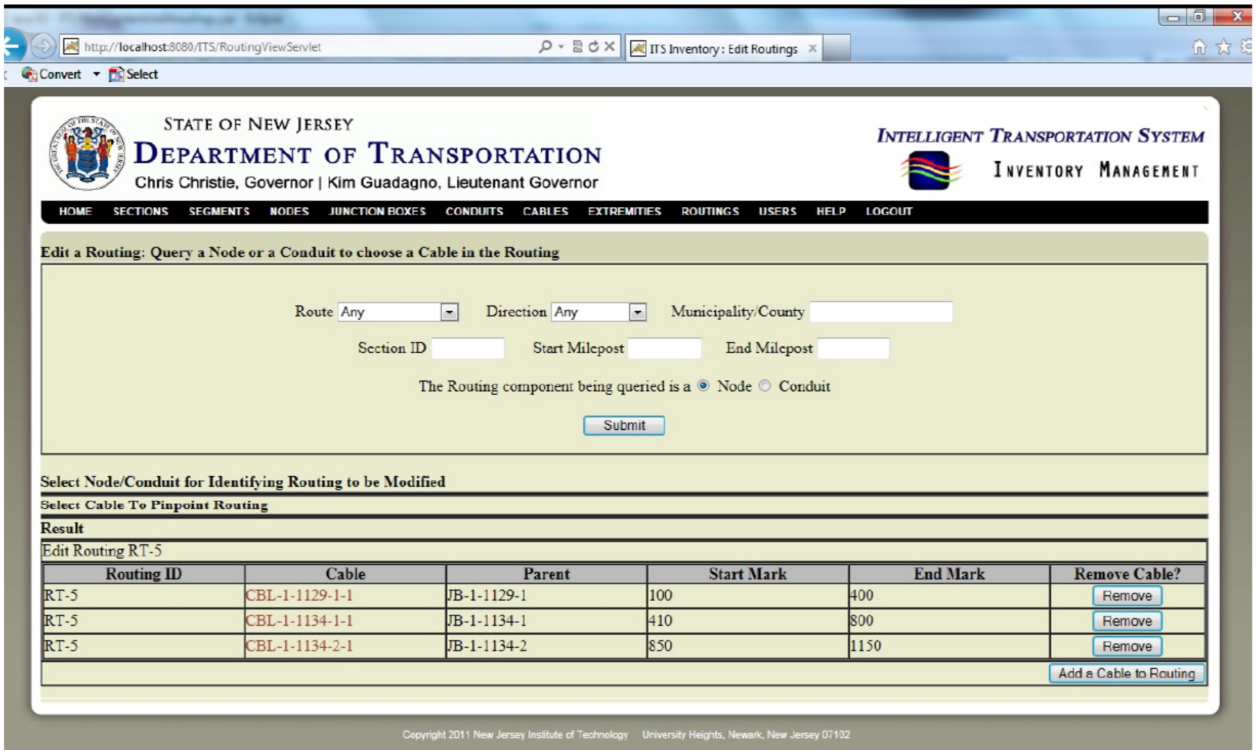

Figure 19. Remove Cable from a Routing Page

The ability to drill-down from a Conduit to its Constituent Cables is shown in the "View Conduit Detail" Page:

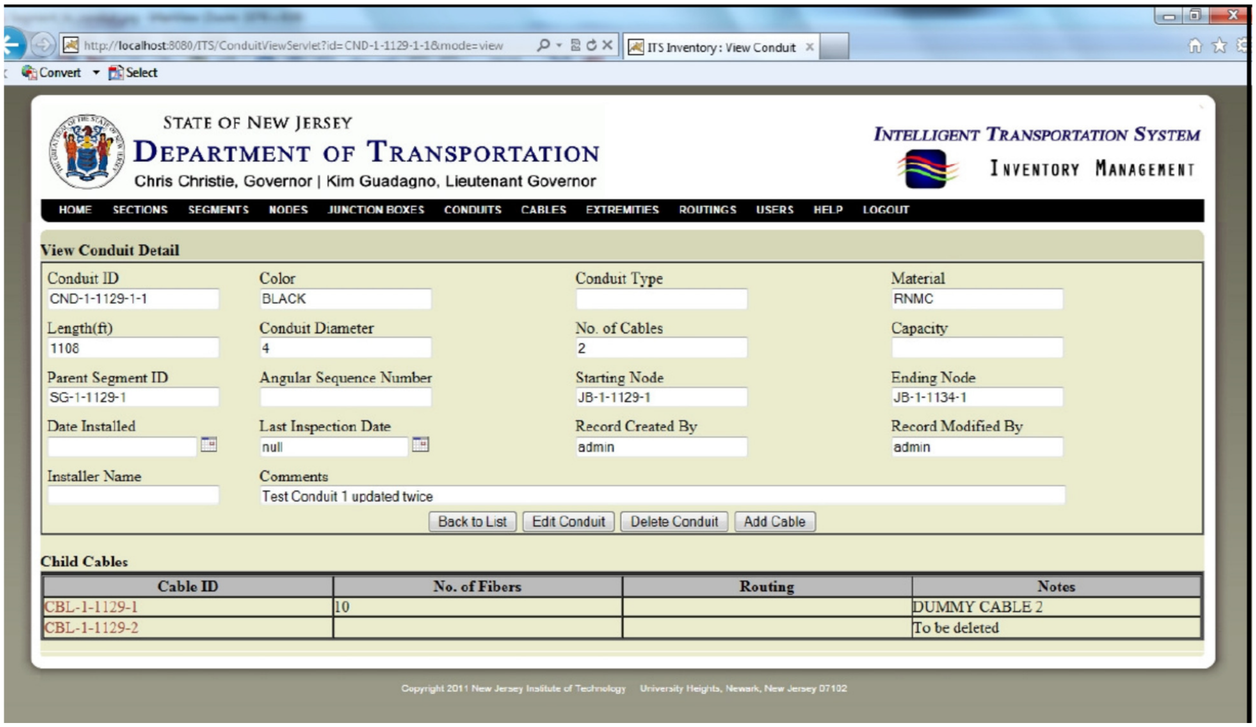

Figure 20. Drill-Down from Conduit to Cables from View Conduit Detail Page

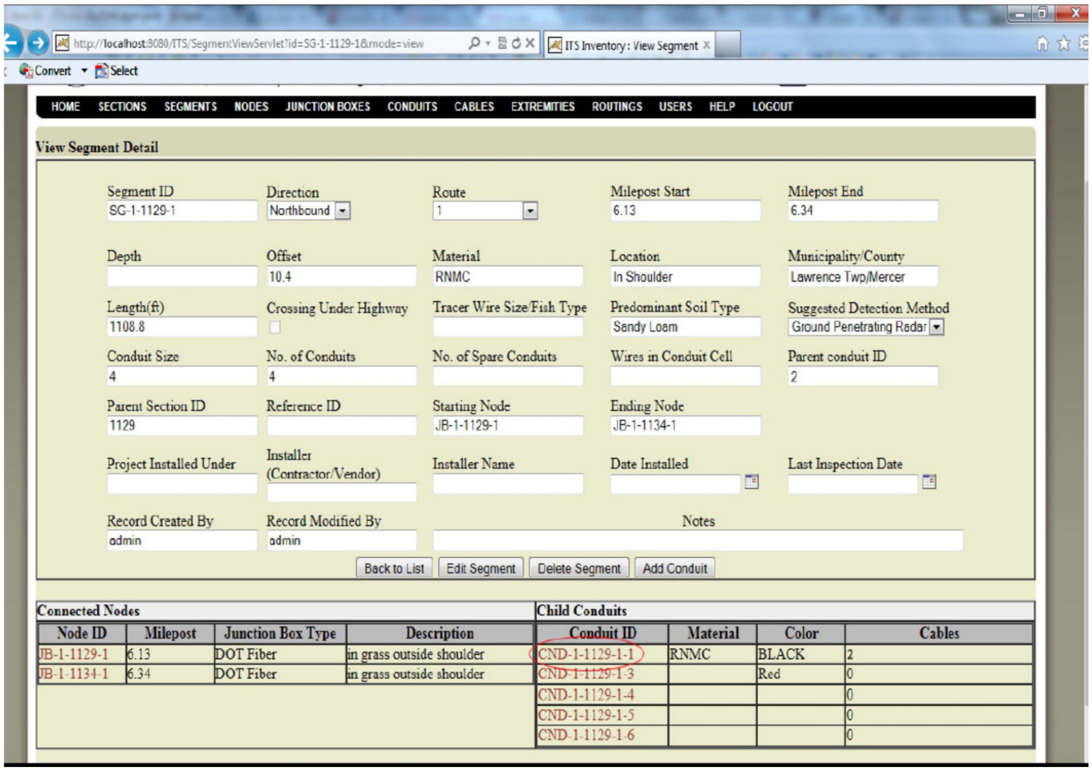

Figure 21. Drill-Down and across to Contiguous Nodes from Segments to Child Conduits from View Segment Detail Page

The manage Users page: this page contains the menu for the different user-related activities.

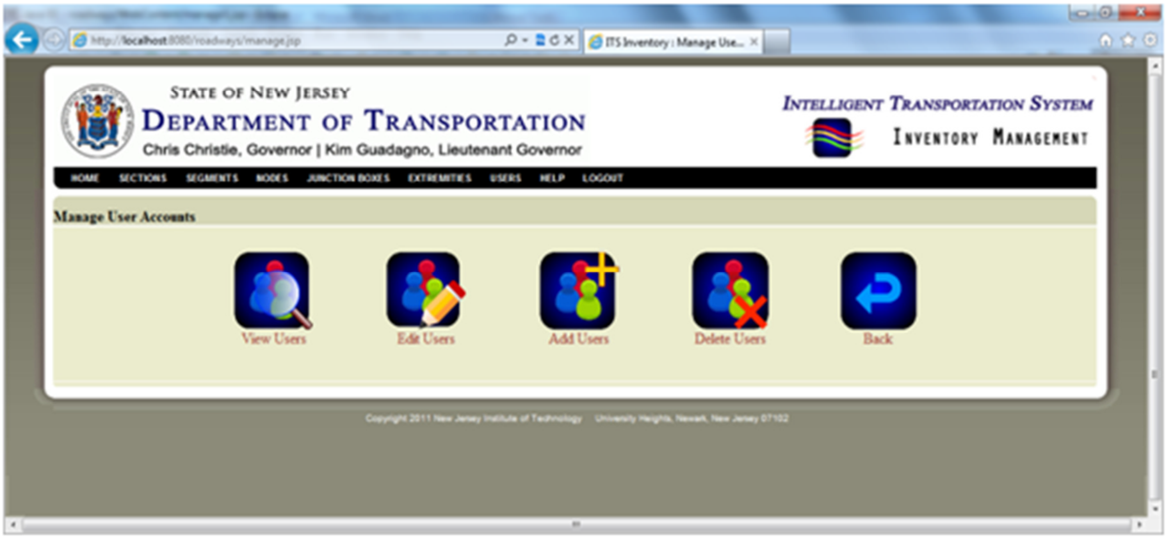

Figure 22. Manage Users Page

The Add user page: this page lets the user create another user account of equal or lower rights. There are two levels of users – those with only view permissions and those with edit permissions. The users without edit permissions do not have access to the create/edit pages mentioned here.

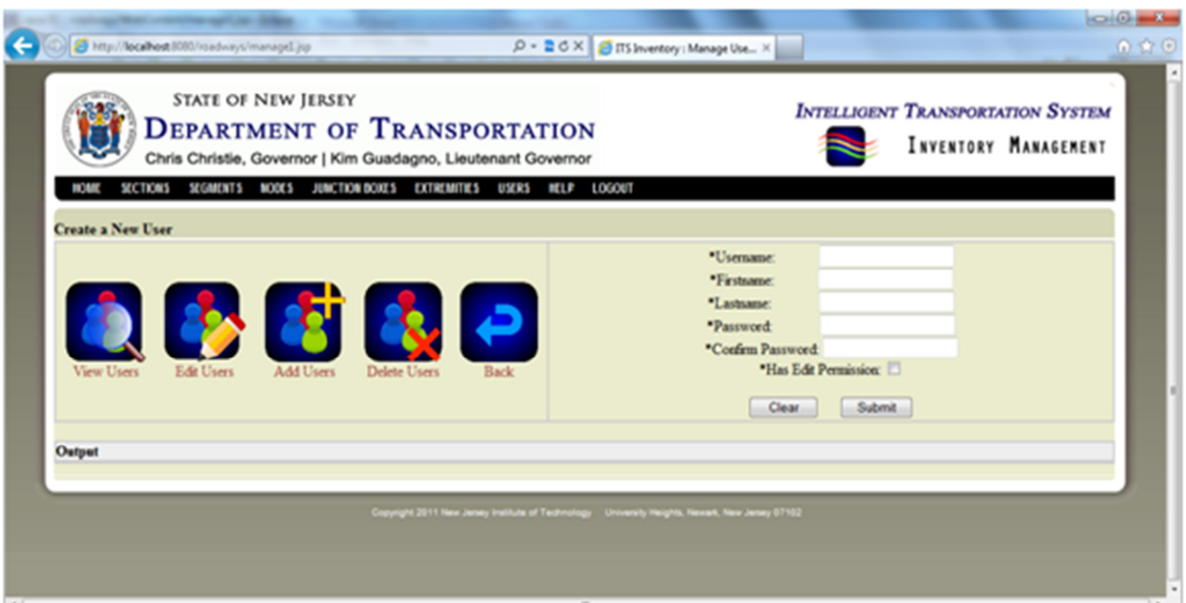

Figure 23. Add User Page

The Edit user account page: this page lets the user edit their own account information (first name, last name, etc), within their level of authorization:

Figure 24. Edit User Account Page

6. Conclusions and Recommendations

Through this work, a process for converting and transforming a flat section-level inventory of fiber optic ITS infrastructure into a comprehensive connectivity-based system was developed and applied in a prototype system. Based on this new design and development effort, a new inventory structure was devised as a basis for a hierarchical asset management system. The system was updated with real yet limited data from field investigations, conducted on a number of major state routes.

The system design inventory includes multiple facility hierarchical layers, an external pipe and Junction Box layer, with proper contiguity relationships, a pipe inner layer of Conduits, and a Conduit and Junction Box inner layer of Cables. Also, a new Construct, the Routing was created to add a connectivity feature to stretches of cables spanning multiple conduits and nodes. Using these constructs and the hierarchical and connectivity relationships, the ability to "drill-down" from an external layer to an inner component and to establish multi-directional facility contiguity is enabled, leading to the progressive improvement of data quality and the establishment of a reliable connectivity model across facilities.

The hierarchical architecture between layers and facilities makes it possible to navigate through various facilities in response to specific queries for construction or repair of external or internal components, and be used for operational, risk management as well as system capacity and strategic evaluation.

The creation of the asset management perspective is the recommended next step for system development, along with an implementation around a target set of State sponsors. The new system functionality would target problem recording, identification, and response, work management, including order planning and monitoring, tracking and recording field investigations for facility location for continuous improvement of the inventory data, and minimization of system disruptions and risks included in digging and maintenance operations of contiguous utility systems.

7. REFERENCES

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