Manual of Guidelines for Inspection and Maintenance of Intelligent Transportation Systems

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Proper installation, care and maintenance of Intelligent Transportation Systems (ITS) equipment increase the efficiency and connectivity of the surface transportation systems, conserve public’s investment in the highway system, and ensure that the system will continue to provide maximum benefits to travelers. Consequences of ITS equipment failures and malfunctions caused by the lack of technical knowledge, inadequate inspection during installation and improper maintenance practices can be “increased motorist and maintenance costs” (unnecessary failures or malfunctions, increasing personnel and repair time, replacement part costs, and spare part inventory requirements), “increased number of accidents” and “increased delays, degraded air quality and fuel consumption”. Prior to this study, NJDOT did not have an inspection and maintenance manual as a reference document to assist NJDOT's inspectors, ITS design, traffic operations and maintenance personnel to minimize the aforementioned problems, to monitor the performance and failure rates, and to provide a cost-effective approach to inspecting, maintaining, upgrading, and operating the ITS equipment on roadways. Rutgers University, in close collaboration with Orth-Rodgers and Associates, Inc., developed a state-of-the art and practical ITS inspection and maintenance manual, and implemented this manual in the form of a user friendly software tool. This tool provides NJDOT with complete, practical and efficient inspection procedures for the proper installation and preventive or routine maintenance of ITS equipment. The initial feedback after several hands-on training workshops from the first group of expert users of the manual and its software is found to be very positive and encouraging.
INTRODUCTION

Intelligent Transportation Systems (ITS) play a vital role in ensuring increased efficiency and connectivity of the New Jersey’s highway transportation system, which continues to evolve in order to respond to the challenges of such an economically vibrant State. Due to the extensive and highly developed roadway infrastructure of New Jersey, which carries heavy traffic of cars and trucks, and given the high-density growth of the region, it is important to ensure that deployed ITS equipment works properly and efficiently. Unnecessary ITS equipment failures and malfunctions due to improper and negligent inspection or maintenance create many problems:

- Waste of time and fuel, a possible increase in pollutant emissions and degradation of air quality due to unnecessary stops and delays,
- Increase in maintenance expenditures (time and monetary) due to repairs and replacement of faulty parts, shortening of the useful life of the equipment,
- Increase in personnel time and spare part inventory requirements,
- Increase in accidents and liability of the responsible agency.

These improper and negligent inspection or maintenance practices occur due to several factors:

- Insufficient Technical Knowledge: The inspectors and maintenance personnel may not have the sufficient knowledge required to inspect and maintain the modern, sophisticated ITS equipment. Another issue is that when the NJDOT expert retires, the knowledge he/she possesses usually cannot be passed to the new personnel.
- Lack of Attention and Poor Documentation: The acceptance inspection and maintenance procedures are often performed with little attention and inadequate documentation so that many problems arise in the future.
- Inadequate Inspection During Installation: ITS equipment problems often can be traced to inadequate inspection during installation which can be due to the lack of comprehensive inspection guidelines.
- Improper Maintenance Activities: The regular care and upkeep of ITS equipment are very important to preserve the intended working condition of the traffic system. This also requires state-of-the-art maintenance guidelines.

Prior to this study, NJDOT did not have an inspection and maintenance manual as a reference document to assist NJDOT's inspectors, ITS design, traffic operations and maintenance personnel. Therefore, there is a need for new tools that will provide the State with complete, practical, and efficient inspection procedures for the proper installation and preventive or routine maintenance of its ITS equipment.

Rutgers University, in close collaboration with Orth-Rodgers and Associates, Inc., proposes to address this need with the objectives below:

- Develop a state-of-art ITS inspection and maintenance manual (ITSIMM) in the form of checklists composed of inspection and maintenance questions for a wide-variety of ITS equipment.
• Develop a computer tool that uses the structure and the knowledge base of ITSIMM to enable users to conduct efficient and careful inspection and maintenance of ITS facilities.

The research team expects that these tools will provide:

• A cost-effective approach to inspecting, maintaining, upgrading, and operating physical assets, such as ITS equipment on roadways,
• Decrease in unnecessary stops and delays, accidents and liability of the responsible agency due to better working ITS equipment and efficient operating traffic at the conflict points (which will in turn decrease waste of time and fuel),
• Decrease in maintenance expenditures (time and monetary) due to:
  ➢ Efficient repairs and replacement of faulty parts,
  ➢ Better recording of the failure rates, monitoring and performance of the personnel and equipment,
  ➢ Increasing the useful life of the equipment,
• Efficient personnel time and spare part inventory requirements which will lower the costs,
• Guidance for transportation professionals that are responsible for developing and maintaining complex Intelligent Transportation Systems and Traffic Management Systems.

Extensive details of this study can be found in the project final report (1). This paper provides an overview of the work Rutgers Intelligent Transportation Systems (RITS) Laboratory research team conducted (2), and it is organized as follows. Firstly, an overview of the research methodology is given. This includes the description and the summary of the well-structured individual interviews with experts identified by NJDOT and surveys conducted. Information about the elucidation of the knowledge from these interviews and surveys is also presented in this section. This is followed by the explanation of the development of manual guidelines using the knowledge representation approach, and the validation and verification of these guidelines with the help of experts. Then, the development of Rutgers Intelligent Transportation Systems Inspection and Maintenance Software (RITSIMS) and subsequent hands-on training efforts are described. Finally, a list of the conclusions and future recommendations suggested by the NJDOT personnel and other experts involved in this project are provided.

RESEARCH METHODOLOGY

In order to obtain comprehensive and state-of-the-art inspection and maintenance tools, the research team needed to:

• Utilize the knowledge and experience related to the maintenance and inspection of ITS equipment which, reside with DOT personnel, consultants, ITS device manufacturers, system vendors, suppliers, and contractors.
• Compile additional information from well-structured comprehensive interviews with experts, manuals, research literature, other DOT’s, FHWA, related web sites, and manufacturers’ published material.

Therefore, the main challenge was to develop an effective methodology to extract the knowledge from a diverse set of experts and sources. This knowledge extraction process could only be achieved using a proven scientific methodology tested for this kind
of problems in the past. An ad-hoc approach based on a series of informal interviews with several of the sources from the private and public sector would definitely fail to produce a high quality and reliable result. The methodology used in other similar projects to capture the expert knowledge of domain experts where the problem domain is large and experts and expertise is scattered was the one called “knowledge base development”.

Since the role of the research team was to define an effective process to capture the expertise of the NJDOT personnel as the main resource, the research team supplemented this with the knowledge that already exists at other DOTs and within the published material by the manufacturers and the suppliers of the ITS equipment. Thus, the research team proposed an intense knowledge base development process that involves the following well-known steps:

- Knowledge Acquisition,
- Knowledge Elucidation,
- Knowledge Representation,
- Validation and Verification of the developed inspection and maintenance guidelines

**KNOWLEDGE ACQUISITION**

This part of the study is called “knowledge acquisition” because it was clear that the knowledge existed in several places and with a number of people in addition to the information that could be found in the published literature. Thus, this became a knowledge acquisition task that had to cover a large span of knowledge domain between the literature and the human experts. This step involved meeting with experts, review of related documents, and site studies to acquire the required knowledge to develop the content of the knowledge base of the manual, and its software implementation. This task was divided into two distinct steps:

**Step 1: Literature Review**

This was the comprehensive review of manuals, research literature, other DOT’s and FHWA’s related web sites, manufacturers’ publications in order to develop a state-of-art ITS inspection and maintenance manual. Therefore, a literature search was performed to identify the experiences of other transportation agencies as well as the private sector. This preliminary compilation of existing research studies resulted in the review of a wide variety of reports and documents including policies of U. S. DOT Federal Highway Administration, Institute of Transportation Engineers, several States (Idaho, Kentucky, Texas, Virginia, Alabama, North Carolina, Minnesota, Arizona, Oregon, Colorado, California, Florida, North Dakota, Oklahoma, Utah, Vermont and Wisconsin) and countries (Ireland, Wales, Scotland and England), the MUTCD guidelines, and private sector reports.

**Step 2: Well-Structured Expert Surveys/Interviews**

As the involvement of experts and stakeholders was vital for the development of a comprehensive and reliable ITS Manual, the development of an efficient strategy for conducting well-structured interviews with pre-determined experts, practitioners, and stakeholders was an important task (3). Therefore, the surveys and interviews were prepared and conducted by the research team according to the protocol-generation
techniques (see (4) for details) aimed at recording the best inspection and maintenance practices from the experts. This was especially very important in terms of capturing the long-term knowledge of experts responsible of related ITS maintenance and inspection issues.

The first stage of knowledge acquisition consisted of sending the preliminary surveys and receiving answers. A stakeholder database was created for the survey participants, and the survey was sent to a number of experts and stakeholders determined in close collaboration with NJDOT project contacts. The preliminary surveys (see (1) for details) included:

- General identification questions (Basic questions about the recipient's involvement in ITS),
- Detailed questions specifically related to ITS inspection and maintenance including:
  - Problem Identification and Verification,
  - Problem Reporting and Assigning,
  - Problem Logging and Tracking,
  - Resource Allocation (Inventory),
  - Prioritization.

The second stage of knowledge acquisition included open-ended face-to-face interviews. The interviewees have been identified from a pool of the NJDOT personnel or contractors that are highly experienced in inspection and/or maintenance of ITS components. The experts interviewed have different areas of interest related with ITS facilities:

- NJDOT Construction and Material Services,
- NJDOT ITS Engineering,
- NJDOT Traffic Operations South,
- NJDOT Traffic Operations Central,
- NJDOT Traffic Operations North,
- NJDOT Inspection,
- DelDOT Traffic Management and Operations,
- DelDOT Signal Maintenance and Construction,
- PennDOT ITS,
- Pennsylvania Turnpike Commission Operations,
- Pennsylvania Turnpike Commission Traffic and ITS,
- Orth-Rodgers and Associates, Inc.
- Private sector companies working with NJDOT (ITS, Traffic Signal and Construction).

The answers of the interviewees to the survey questions prior to the face to face interviews made the research team familiar with the job duties of each interviewee as well as the work experience and areas of expertise each one possesses. This also allowed the interviewer to tailor the questions to the interviewee’s specific expertise, which maximizes the effectiveness of interview process and minimizes the time it takes to conduct each interview. The meetings mainly served as a mean for gathering information about the current state-of-practice of inspection and maintenance processes for various ITS equipment. The interviews included:
• Reviewing the materials while soliciting comments in an open forum arrangement,
• Defining the problems that arise during the inspection and maintenance of ITS equipment in both private and public sectors,
• Discussing the structural breakdown of the manual regarding the main issues in ITS inspection and maintenance,
• Going over the inspection and maintenance questions one by one to ensure the accuracy of the manual,

After these meetings, all the information obtained was processed and formalized in a written format. Other meetings were arranged to discuss the results of the knowledge acquisition efforts so far, to discuss follow-up questions, to concentrate on major issues, and to obtain a consensus for the next stages of ITSIMM.

Moreover, Orth-Rodgers and Associates, Inc. (ORA) conducted several meetings with engineers and experts in their company, and with representatives of transportation agencies at other States. As part of this effort, two meetings have been handled by ORA with Pennsylvania Turnpike Authority, and Delaware DOT. Attendees were asked to review the material provided and to submit comments and suggestions back to ORA.

KNOWLEDGE ELUCIDATION

This step involved processing of expert knowledge in order to clarify different aspects of the knowledge acquired from the experts and other cited resources.

Literature Review Results

There has not been one commonly accepted comprehensive inspection and acceptance manual for Intelligent Transportation Systems in the literature. The literature mostly included design, installation, and operation manuals or details for ITS equipment (5-16). Moreover, some partial manuals did exist in some States like the one in North Carolina in the form of maintenance checklists for Variable Message Signs (17) and in Alabama in the form of maintenance check specifications for Portable Changeable Message Signs (18). Dudek et al. (19), (20) conducted several studies for the operations and improvement of Variable Message Signs. The working papers published by the universities or other private and/or public agencies for the improvement of ITS facilities in a specific region also had great importance for determining the basic concepts of ITS inspection and maintenance procedures (21-24). Moreover, ITS Primer published by ITE (25) provided valuable information about ITS equipment, their functions, and components. The most comprehensive documents for the inspection and maintenance of ITS equipment were the Traffic Control System Operations Handbook published by Institute of Transportation Engineers (ITE) (26), and the Testing Handbook for Transportation Management Systems published by TransCore (27). These handbooks presented a general tutorial to familiarize manual users with fundamental concepts for the inspection and maintenance of ITS equipment. There were also several maintenance checklists for different types of ITS equipment published by the manufacturers, departments and subcontractors (28-32). For instance, Edwards and Kelcey had maintenance checklists with rating systems (28). The manufacturers had also checklists that might not be applied for other brands of the same equipment as they were mostly equipment specific.
Expert Survey and Interview Results

The results of more than 20 interviews, with each interview not lasting less than 2 hours, were processed in this step. The surveys and expert interviews provided significant information used in the development of ITSIMM by going over all the existing checklist questions and improving these questions with their suggestions and expertise. Experts that were interviewed provided a number of comments and problem specific information to each section of the preliminary inspection and maintenance checklists prepared as part of the well-structured knowledge acquisition process. Most significant parts of these contributions are summarized as follows:

1. There is a need for the development of an electronic data display and collection system for the inspection and maintenance of ITS equipment. This software application could be implemented on a touch-screen “tablet” notebook computer.
2. The manual should work as a uniform and consistent guide to the installation, inspection and maintenance of ITS facilities.
3. There is a need for a rating system for the maintenance questions.
4. The questions in their current format were considered as adequate as a detailed explanation for each question was not necessary. As suggested, the action item should only be made to inform the operations or maintenance center most of the time.
5. There is a need for separation of maintenance procedures into separate sections namely, preventive and routine maintenance.
6. Pre-construction inspection checklist was added to the inspection guidelines.
7. Several questions were deleted as they were either irrelevant or unnecessary; several others were added/revised by the interviewers regarding their knowledge and experience.
8. Brand specific checklists were considered as not necessary as the manufacturer’s specifications and manuals are already being used by the departments.
9. Maintenance checklists for common components were relevant to the scope of the manual.
10. The communications and distribution systems were combined under one umbrella.
11. Failure reports were added at the end of inspection and maintenance procedures.

One of the more general outcomes of the interviews was that the ITSIMM would serve as a guideline for inspection and maintenance personnel of NJDOT. The interviewees agreed on the proposed structured breakdown of the overall process into pre-inspection, construction inspection, preventive maintenance, and troubleshooting sub-processes. Moreover, the experts pointed out that inspection and maintenance crews had limited resources compared to the number of individual ITS installations dispersed over a large geographic area. Therefore, NJDOT personnel could be more efficient and effective by using their time and resources if they had a computerized version of ITSIMM namely, RITSIMS. Another important point was that the current reporting procedures required the operations staff to check the operation of each piece of equipment frequently. A written report was generated and given to the shift supervisor who enters problems into a database, and then an electronic form was generated from the database which was distributed to management. Thus, the experts mentioned that there was an urgent need for better reporting capabilities that can also be incorporated into RITSIMS which can be run on a touch screen laptop or tablet PC.
KNOWLEDGE REPRESENTATION

This task was completed through the development of material including procedures, checklists and guidelines using the expert knowledge obtained and processed in the previous stage.

Development of Manual Guidelines and Sections

As ITSIMM should assist NJDOT personnel in efficiently conducting inspection and maintenance of ITS equipment, the manual was designed in a way that can be easily comprehended and used.

The overall research methodology employed in this study is shown in FIGURE 1.

ITSIMM is composed of three main sections/components namely, inspection, maintenance and troubleshooting of five categories of ITS equipment based on their functions and usage as shown in FIGURE 2.
The inspection and maintenance procedures for five categories of ITS equipment are illustrated in FIGURE 3. Basically, the idea of the inspection checklist is to determine the criteria that fail for the ITS equipment that is being inspected. In other words, this is a binary pass or fail rating system that focuses on the success of the list of criteria determined for each ITS equipment. Therefore, the complete satisfaction of the acceptance/inspection criteria has the utmost importance. On the other hand, for the maintenance operations, there is a rating system for the questions included in the checklist. That is, the action should be taken according to the degree of maintenance required. This concept of rating the current condition of each ITS equipment is used in all the maintenance checklists.

The manual consists of 17 inspection checklists and 42 maintenance checklists, where each checklist serves for a different ITS equipment. The inspection checklists include an average of 10 questions for each equipment, whereas maintenance checklists require about 15-20 questions to be completed.
Inspection Procedures

The inspection checklists provide general guides, and should be used as supplements to, not replacements for the contract specifications and specific installation instructions of the product manufacturers and suppliers. The elements of inspection are given as:

- **Pre-Construction Phase**: A simple pre-construction check should serve for the purpose of making any field modifications to the plans when necessary to fit site conditions.
- **Basic ITS Elements**: These include the inspection of conduits, junction (pull) boxes, loop detectors, foundation, CCTV poles, VMS sign supports and sign boxes, wiring and grounding, and the communication/field equipment cabinets.
- **Electric Service**: The components associated with providing electric service are: pre-construction electric service, service poles and electrical feed, and load center and meter.
• **Traffic Maintenance during Construction:** A traffic control plan should be properly implemented and revised if necessary to conform to the prevailing field conditions.

**Maintenance Procedures**

ITS are often designed and installed with little attention to the future maintenance requirements. This problem has been magnified in recent years by the increasing complexity of ITS components and lack of standards. It is significant to perform maintenance procedures effectively so that the costs incurred for providing maintenance and training staff can be minimized. The maintenance procedures are listed as follows:

• **Generic Routine Maintenance:** Typical daily checks, adjustments and minor component replacement. General questions irrespective of the equipment brand are included here.

• **Generic Preventive Maintenance:** It is defined as a set of checks and procedures to be performed at regularly scheduled intervals for the upkeep of ITS system, including maintenance, record keeping, cleaning, and replacement based on the function and rated service life of each component. It is irrespective of the equipment brand.

• **Brand Specific Maintenance:** This approach includes the specific questions for different brands (Daktronics, Vultron, etc).

• **Common Equipment Maintenance:** Questions related to the equipment common to all devices belong to this category.

With this idea, tables in the form of checklists are developed as an attempt by the research team to summarize various approaches found in the literature. In these checklists, a rating system has been applied as a result of the expert meetings. Depending on the completion of the task, there are four available ratings:

1. **Excellent:** Totally Operative / New
2. **Good:** Operative / Satisfactory
3. **Fair:** Operative / Needs Minor Work
4. **Bad:** Not Operative / Needs Major Work

**Troubleshooting**

Based on the field experience of NJDOT engineers, it is determined that it would be useful to have some common troubleshooting measures which will help one to solve the problem that appears during the maintenance checks. Since trying to find the problem and its solution can be difficult and time consuming, the idea of troubleshooting has utmost importance for ensuring the efficient operation of any ITS equipment. To achieve this goal, troubleshooting tables for individual ITS devices are prepared that basically include some basic sample problems/symptoms, their possible causes and remedial actions for the mentioned equipment.

**VALIDATION AND VERIFICATION**

Most of the information given in the manuals is highly technical and procedural, and therefore it is important to verify and validate this information very carefully before actually using it.
Upon the development of various products including ITSIMM, its checklists, the RITSIMS software, and the training content, they were evaluated by the experts and its developers to ensure their accuracy and appropriateness for the tasks they are designed for. Depending upon the results of this step, the research team decided whether or not to go back to Knowledge Acquisition and Knowledge Elucidation steps, and to make changes. This step was done using problem domain experts who are able to give practical advice about any proposed procedures. Therefore, during/after obtaining the draft version of ITSIMM, the manual was constantly revised by the experts from NJDOT, private companies, and other state authorities. The comments of the experts obtained several times for different versions of the manual were used to verify the efficiency and effectiveness of the ITSIMM and RITSIMS.

DEVELOPMENT OF RUTGERS INTELLIGENT TRANSPORTATION SYSTEMS INSPECTION AND MAINTENANCE SOFTWARE (RITSIMS)

Description

RITSIMS has been implemented in Visual.Net language using the main guidelines obtained through the knowledge base development process for ITSIMM. RITSIMS requires a minimum of 3 MB disk space when the databases are empty. Therefore, the moderate space requirements of RITSIMS give a flexibility to make it work easily and efficiently in different computer environments. RITSIMS has been revised and/or updated several times after receiving the feedbacks from experts.

The manual guidelines implemented in RITSIMS have several advantages as summarized below:

- With RITSIMS, DOT personnel can easily perform inspection and maintenance of any ITS equipment using a laptop computer or a tablet PC.
- Detailed information of each inspection and maintenance performed is automatically recorded in the appropriate databases.
- The equipment list database includes specific details for the selected ITS equipment, such as the location, age and inspection details.
- Troubleshooting option enhances the on-site process of solving simple yet frequently encountered equipment related problems.
- At any time, it is possible to add/delete new equipment items and questions.

System Requirements and Installation

RITSIMS is compatible with Windows 98/2000, Windows XP and Windows Vista. The application procedure requires minimal effort, and can be started by clicking on the MTSoft.exe file that is supplied in the MTSoft folder. The software uses Microsoft Access databases to store the user and equipment details, results of the inspection and maintenance checks, and histories. This environment works extremely well enabling the fast and efficient usage of the software. All the database files (.mdb’s) are accessible in the same MTSoft folder.

Functionalities

There are twelve basic parts of RITSIMS to be studied briefly:
• **User Details:** This is the place where the user should select the user name and password to use the other functionalities of the software.

• **Equipment Selection:** There are five different types of equipment (see FIGURE 2).

• **Option Selection:** After selecting the equipment, the choice of inspection or maintenance comes. Troubleshooting is available at any time regardless of the equipment selection.

• **Location Selection:** The equipment database includes the locations of the equipment. Therefore, the inspector can select the equipment from the drop-down box of locations.

• **First History Information:** After selection of the equipment, it is possible to see a brief previous history of that equipment. For instance, one can see the inspection details of the equipment while doing the maintenance for the same equipment later on.

• **Component & Option Selection:** The component to be inspected can be selected separately in this section. For the inspection, selecting the component is sufficient. However, for the maintenance procedures, one should first select the maintenance options, then he can choose among the components of the ITS equipment.

• **Inspection & Maintenance Questions:** Here, it is possible to answer the inspection or maintenance questions in the checklists.

• **Report:** Here, it is possible to see the detailed report obtained for inspection or maintenance performed to ITS equipment. The report includes:
  o Type of Equipment and Work Performed (Inspection or Maintenance),
  o Inspection/Maintenance Details (Inspection/Maintenance Date and Inspector Name),
  o Answers to Checklist Questions,
  o User Comments.

• **Printable PDF Version of the Manual:** At any time, checklist questions for the equipment can be printed. This is useful when a computer is not available for use in the field.

• **Pausing:** This option is available for short-term and long-term pauses throughout the inspection and maintenance procedures.

• **Database Synchronization:** The database tables obtained during the inspection and maintenance procedures in the field can be sent to the master database which is located in the main computer at the office. The synchronization can be done both ways to ensure that all the computers used for the inspection and maintenance checks have the latest version of the database tables.

• **History and Queries:** The history and queries (location, user, date, and equipment based) can be accessed any time by the approved users (i.e. supervisors, system coordinators), and answers to the checklist questions can be changed at any time.

**Work Flow and Structure of RITSIMS using ITSIMM**

With the aforementioned guidelines, a work flow and structure have been developed to make use of checklist questions. Basically, RITSIMS uses a number of databases to access the equipment lists and question checklists. The equipment list database includes the specific details for the selected ITS equipment, such as the location,
After selecting the equipment, there are three basic choices namely, inspection, maintenance and troubleshooting. Upon selection of one of these choices, the generic checklists for that choice appear, and the user will be able to check the equipment and subsequently will see the list of corresponding questions saved in the checklist database. There are also brand specific and common element checklists which improves the efficiency of the process. Moreover, the troubleshooting section contains a number of simple and basic sample problems, and their possible causes. All the results are saved into the database of either the portable device or the main computer for future use.

The overall structure of the work flow is given in FIGURE 4.

**FIGURE 4 ITS Inspection and Maintenance Manual (ITSIMM) Work Flow and Structure**

### Description of the Database Structure of RITSIMS

The diagram which depicts the database structure of RITSIMS is shown in FIGURE 5. The databases are in Microsoft Access format so that they can be easily modified and revised in the future. At the end of each inspection or maintenance process, all the results are saved into the database of either the portable device or the main computer for future use. RITSIMS is designed to be capable of both allowing to check the equipment with a computer or hand-held device and also to make it possible to update the main database of the ITS equipment using the new information saved into the field computers. The equipment/location database now includes 196 pieces of ITS equipment, namely 124 cameras, 63 variable message signs, and 9 highway advisory radios, which are supplied by NJDOT traffic operations north region. Moreover, since the databases are
in Microsoft Access format, they are not hard coded in the software. This makes it very easy to perform updates or changes in the database with a basic Microsoft Office knowledge.

![Database Diagram](image)

**FIGURE 5 Database Diagram**

**User Interface Screenshots of RITSIMS**

User interface screenshots from an inspection procedure in RITSIMS is shown in FIGURE 6 where an inspection is being performed for a Closed Circuit Television System (CCTV) located at the intersection of Route 1 and Route I-287 in New Jersey.
FIGURE 6 Screenshots from RITSIMS Inspection of a Closed Circuit Television System
Feedback and Enhancements

RITSIMS has been tested by experts to obtain feedback. As a result of these tests, several changes have been implemented. These are:

1. The detailed information of each inspection and maintenance performed is now recorded in the appropriate dedicated databases.
2. The equipment list database now includes specific details for the selected ITS equipment, such as the location, age, and inspection details.
3. Troubleshooting is made accessible any time regardless of the equipment and option selected to enhance the on-site process of solving simple yet frequently encountered problems.
4. At any time, it is now possible to add/delete new equipment and questions.
5. The brand specific checklists are considered not necessary as the manufacturer’s specifications and manuals are already being used by the department.
6. Two pause options are created: short-term and long-term.
7. The equipment location information/user interface and selection options are revised.
8. The printable manual checklists saved in PDF format are made accessible in the software to enable the users to conduct their inspection and maintenance duties even when a laptop is not available to them.

RITSIMS was also tested by RITS lab graduate students who, have not worked on the project up to that point. This unfamiliarity with the software was expected to allow the research team to debug RITSIMS more efficiently. A number of simple scenarios were designed and students were asked to execute them to test the software’s robustness as well as its ease of use. This process was repeated by various students several times to simulate continuous use of this tool by the field personnel. They were also asked to document their perception of the ease of use of RITSIMS and the bugs they encountered. They provided valuable feedback by which some of the software bugs were identified and addressed. For instance, user-interface and reporting procedures were revised based on the number of issues raised as a result of these tests.

There has been a common consensus among the users of RITSIMS that it should provide a very comprehensive database that not only provides a series of checklists of installed device maintenance records, but also a capability to track maintenance activities and an inventory of the spare parts of specific device types. Moreover, agencies which participated in the testing of RITSIMS provided very positive feedback regarding its usefulness and repeatedly suggested that the software and the database can also be used as a maintenance scheduling tool. All these will be part of future work.

User Manual and Training

A comprehensive user manual for RITSIMS was also prepared and submitted to NJDOT. This manual included all the key features and functionalities of the software.

Furthermore, extensive training sessions of RITSIMS were held for the NJDOT traffic operations, inspection and construction (north, south and central regions) personnel. More than 30 NJDOT personnel attended these initial training sessions.

These training sessions were held in the form of two basic sessions:
In the first session, a brief introduction about the study was given to the attendees. The functionalities of the software were introduced, and several inspection and maintenance example checks were interactively performed.

In the second session, the basic features of the software were shown to the attendees using case-based scenarios. These scenarios included:
- Inspection,
- Maintenance,
- Updating (Inspection & Maintenance Answers),
- Troubleshooting,
- Database Synchronization,
- History Checks and Queries.

The case-based scenarios for inspection and maintenance procedures using RITSIMS were given to the attendees and they successfully performed both scenarios. During/after the training, comments and suggestions of the attendees were also solicited to identify possible future improvements.

CONCLUSIONS AND FUTURE WORK

This study developed a state-of-the-art Intelligent Transportation Systems inspection and maintenance manual (ITSIMM) and Rutgers ITS inspection and maintenance software (RITSIMS) based on ITSIMM that is expected to serve as a reference document to assist the NJDOT personnel in their daily activities of inspection and maintenance of ITS equipment. The vast amount of knowledge has been extracted and then incorporated into ITSIMM from knowledgeable, experienced DOT personnel and well-trained inspectors and/or subcontractors. Therefore, ITSIMM has been created as a comprehensive reference document that has separate inspection (acceptance), maintenance and troubleshooting sections. These comprehensive guidelines have been implemented in RITSIMS with these specific characteristics:

- A user-friendly interface for the usage of any personnel (rather than being an expert on the subject),
- A unique system to perform all the inspection and maintenance checks of ITS equipment from the beginning to the end on site,
- A simple database system that can allow further changes and queries,
- An efficient database synchronization system to ensure the up-to-dateness of all the computers used.

These tools will create cost-effective solutions to many ITS-related problems by:

- Implementing efficient inspection, maintenance and troubleshooting practices,
- Monitoring the performance of the personnel and equipment,
- Increasing the useful life of the equipment and keeping inventory costs lower,
- Scheduling the maintenance activities and recording failure rates in a more professional way.

The initial feedback from the first group of expert users of the manual and its software was very positive both in terms of its operational approach and user-friendly interface. Currently, NJDOT is conducting a pilot test of RITSIMS to ensure its long-term usage as their main ITS maintenance and inspection tool. Research team is closely working with NJDOT to set up a filed implementation of RITSIMS in the near future.
There are several recommendations that can be implemented to enhance the RITSIMS. Among these, most promising ones are:

- Addition of new functionalities related to the warranty, factory testing information, as well as the record of spare parts, and frequency and cost related issues after obtaining the required data.
- The idea to use RITSIMS to be driven by the site location of the equipment with the appropriate checklists compiled among the database of checklists for that site.
- An additional module for allowing addition/deletion/changes to the questions inside the software.
- A GIS-based implementation of the RITSIMS.

ACKNOWLEDGEMENTS

This project was funded by a grant from NJDOT and administered by Rutgers Center for Advanced Infrastructure and Transportation (CAIT). Their support is both acknowledged and appreciated. We would like to thank Tiberiu Tajts and Edward Hanna of NJDOT for their invaluable contributions to the success of this project from its inception to the completion of the final report.

We would also like to thank the interviewees. The project would not have been completed without the cooperation of the survey respondents and interview participants who graciously contributed their time and expertise to the study.

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