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Culvert Information Management System (CIMS)
Pilot Demo – Phase II

FINAL REPORT
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and
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Federal Highway Administration

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16. Abstract

A pilot scale Culvert Information Management System (CIMS) was developed for the New Jersey Department of Transportation (NJDOT) Maintenance Division to serve as an integrated culvert information reporting system to address the problems of accessing and analyzing the large amount of information regarding culverts in use in New Jersey. This report outlines the tasks and objectives undertaken to enhance the previous NJDOT pilot scale Culvert Information Management System (CIMS Phase I) into the current CIMS Phase II through integration and customization of culvert inspection data from vendors to improve the overall functionality of the system. The enhanced pilot scale CIMS Phase II software application system consists of three major software components:

- Databases
- User Interfaces
- Access Data Administration Module

Using available data on DVDs provided by contract vendors, the CIMS application has been updated and enhanced to provide a representation of a future large-scale CIMS system for NJDOT use. The current CIMS application contains an up-to-date inventory of over 8,500 culvert infrastructure assets throughout New Jersey. The survey also conducted an analysis of VHS tapes from old inspections to provide a cost and time estimate to update and upload the data into CIMS. The system has the capability to generate customized NJDOT quarterly reporting based on queries and parameters specified by the user. This report also provides recommendations and proposals for future versions of the CIMS application to make it all-inclusive and convert the current CIMS system into a pilot scale online web-application/database with a data submission system, maintained by NJDOT, for the NJDOT vendors. Hands-on training will be provided to NJDOT in the use of the developed procedures.

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LIST OF ABBREVIATIONS AND SYMBOLS

Condition State	CS
Corrugated Steel Culvert Pipe	CSCP
Culvert Information Management System	CIMS
Federal Highway Administration	FHWA
Frames per Second	FPS
Governmental Accounting Standards Bureau	GASB
New Jersey	NJ
New Jersey Department of Transportation	NJDOT
Quality Control	Q/C
Video Home System	VHS
Sequential Query Language	SQL
Straight Line Diagrams	SLD
National Water Main Cleaning Company	NWMCC
Mount Construction Company	MOUNT
Cook Inc.	COOK
Central Processing Unit	CPU
Active Server Processing	ASP

INTRODUCTION

The New Jersey Department of Transportation (NJDOT) recognizes the significant problem of analyzing the large amount of culvert data from the state's drainage system with respect to its condition and installation date. Inspections of many older culverts have shown a deteriorated condition state, leading to installation areas likely to result in erosion or collapse. This issue must be addressed within the next several years to prevent costly infrastructure repairs and failures to New Jersey roadways.

Culvert Information Management System (CIMS) Phase II is capable of analyzing and reporting on assets conditions and recommending inspecting, rehabilitating/ replacing, or doing nothing at both project and network levels. At the project level, this is achieved by comparing inspection and/or rehabilitation/ replacement costs with risks and costs associated with failure. At the network level, the associated costs are optimized to meet annual maintenance budget allocations by specifying the priorities of assets that need inspection and rehabilitation/ replacement. CIMS can also be used to estimate the required annual budgetary allocation for planning, maintaining or improving the condition state of the culvert system, or to maintain or improve the total highway corrugate steel culvert pipe (CSCP) network asset value, thereby meeting the Governmental Accounting Standards Bureau (GASB-34) requirements.

The enhanced CIMS Phase II inputs all the data gathered from the various vendor culvert inspection DVDs to make the CIMS current so as to:

- Customize CIMS to generate quarterly reports to NJDOT upper management.
- Develop a data translation program to populate the CIMS from different inspection systems.
- Conduct a reconnaissance of the culvert data provided for all old inspection contracts and provide a cost and time estimation to update and upload that data to CIMS.

The following task discusses in detail the procedures and methods used to develop, test, and maintain the CIMS system

Task 1: ENHANCE CIMS DEMO DATABASE

Using available data on DVDs provided by culvert inspection contractors, the pilot CIMS has been updated and enhanced to improve functionality and provide a representation of a future large-scale CIMS system for NJDOT use.

Data was supplied to New Jersey Institute of Technology (NJIT) from three inspection vendors for NJDOT: National Water Main Cleaning Company (NWMCC), Mount Construction Inc, (MOUNT), and Fred A. Cook Jr., Inc. (COOK). All current and potential inspection contractors are required to follow specific data preparation specifications that will allow integration of inspection data into the CIMS system. The three main categories for the information include the culvert pipes, inlet/outlets structures and observation data. Testing the current data involved several revisions to the CIMS application software in order to generate accurate results by optimizing procedures for future use. It is very important that potential contractors provide data with consistent output format.

Task 1.1: Upload All Culvert Inspection Data on DVDs to Make CIMS Current and Update the SLD Database

Current DVDs' data have been uploaded to the CIMS Phase II program running on an external hard drive. The uploading procedure has been tested with all current available information and has shown to be running effectively and efficiently. With uploaded data, the CIMS database currently contains the following records:

Table 1 - CIMS Database Inventory

NWMCC:	6,711 culverts, 6,527 inlet/outlets
MOUNT:	2,317 culverts, 3,190 inlet/outlets
COOK:	804 culverts, 951 inlet/outlets

Based on the current uploaded inventory, the NWMCC contains 6,711 culvert records along with 6,527 inlets and outlets records. The Mount Construction Company (MOUNT) database contains 2,317 culverts along with 3,190 inlets and outlets records. The Cook Inc. (COOK) database contains 804 culvert records and 951 inlets and outlets. The number of culvert records and inlet/outlets records were extracted from the 'da_pipe' Access table and the 'da_pipe_struct' Access table, respectively.

The following steps outline the procedure utilized to upload Culvert Inspection Data from the DVDs into the CIMS system:

1. **Locating the CIMS Application.** Browse to the path and folder labeled 'CIMS' found on a provided hard drive or server (ex. F:\CIMS) and double-click to open the CIMS application file named 'CIMS_Application_2008'.

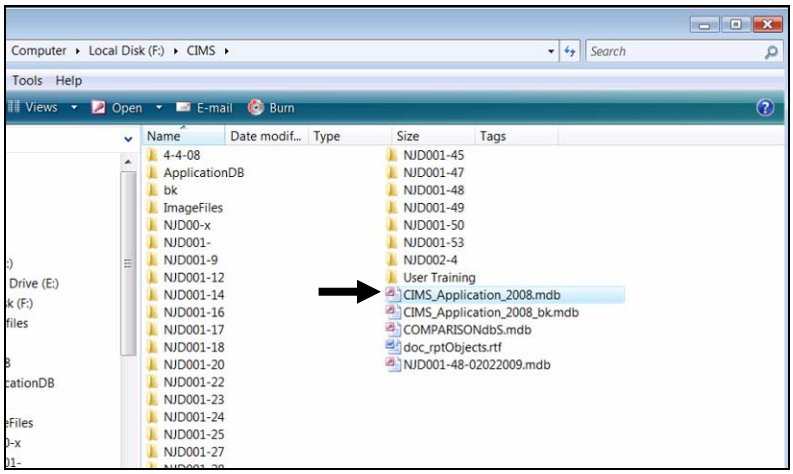


Figure 1 - CIMS Directory.

2. **Using the CIMS Application.** The CIMS application will open up as an interface within Access with the Main window displaying the following options: Inlet/Outlets Structures, Culvert Segments, Data Administration, Keyword Tables and Quit command (see Figure 2). Click on the 'Data Administration' button to begin the uploading process.

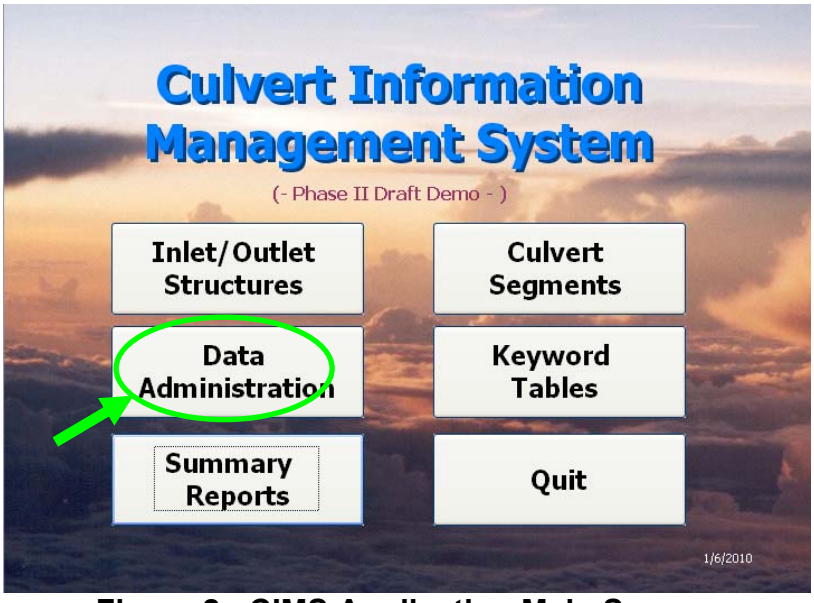


Figure 2 - CIMS Application Main Screen.

The main window in CIMS allows users to upload data and view/modify records for Culvert segments and Inlet/Outlet Structures. The Keyword Tables allows users to view and modify definitions and input parameters for the data fields.

Figure 3 - CIMS Application – Data Administration window

After clicking on the 'Data Administration' command, the following window will open with the following options: Upload New Records, Clear All Tables and Close Me. First, click the 'Clear All Tables' button to clear existing data and then begin uploading new data by clicking the 'Upload New Records' button.

3. **Data Uploading.** In the following 'Data Uploading and Manipulation' window, click the 'Go' button and then click 'Yes' for the pop-up warning box to specify the Database and Photo File Directory containing Culvert Inspection Data.

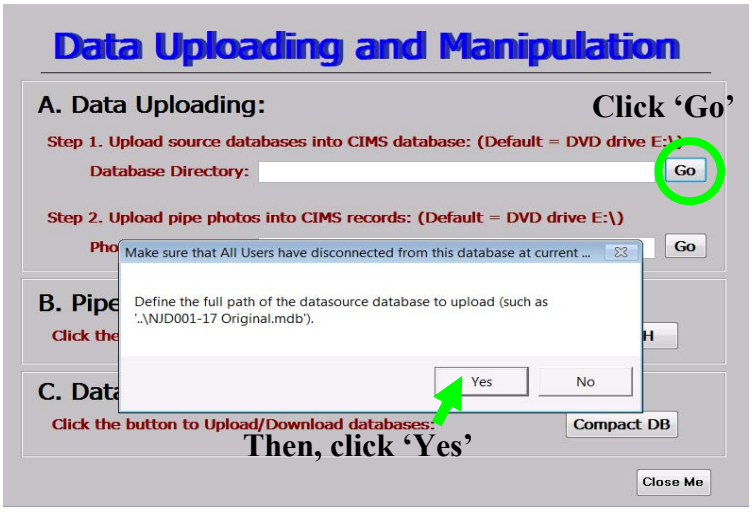


Figure 4 - Data Uploading window and confirmation window

4. **Locating and Specifying Source Data directory.** Locate the path and then double-click to open a vendor folder containing the uploaded DVD data (ex. F:\DVDs). Within each contract folders are separate folders for each inspected route, labeled by Route Number and City. Select and open a Route folder to upload its source data (i.e.. F:\DVDs\Mount Database\Rt. 1 MP15-16 - South Brunswick, NJ.mdb). The folder contains an Access database file for the route and a Photos folder.

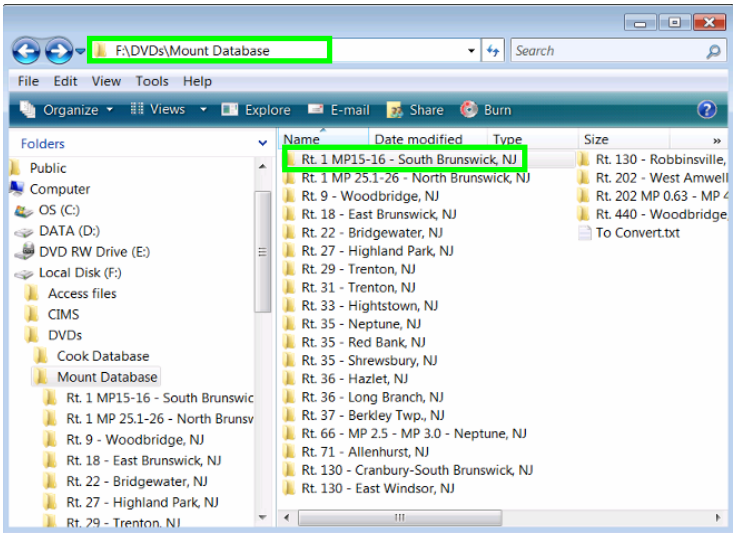


Figure 5 - Mount database directory

5. **Specifying Data Source Identity.** Click 'Yes' in the following prompt window if the source database is from a 'Mount Construction' database, otherwise click 'No'.

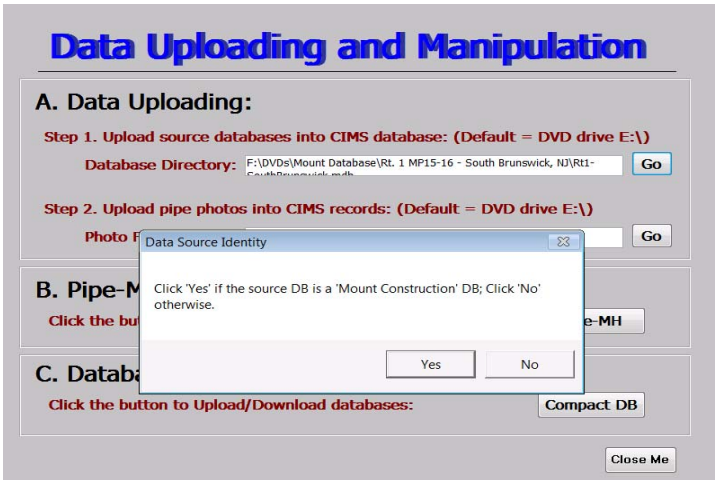


Figure 6 - Data Source Identity window

6. **Review data before uploading.** Check the selected source data in the review window to make sure that all appropriate fields are filled in and then click the 'Uploading' button to begin the uploading process. A prompt window will confirm that data have been uploaded and automatically

append valid data records from the source database into CIMS database tables.

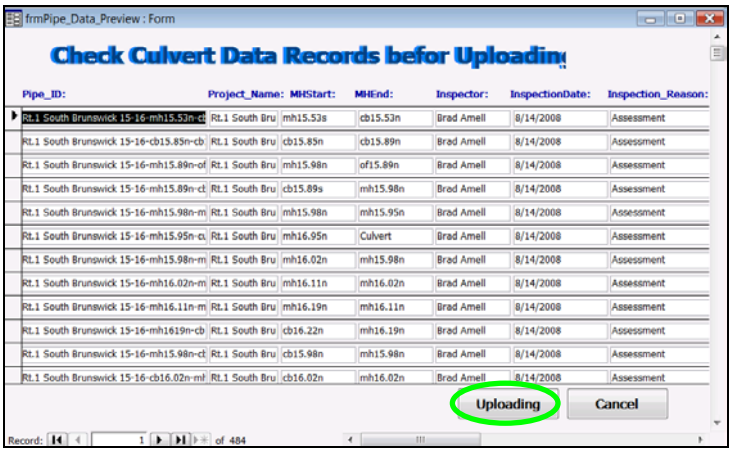


Figure 7 - Culvert Data Records preview form

7. **Upload all route database sources of a contract.** Repeat the uploading process for each Route data by specifying the 'Database Directory' and 'Photo File Directory' fields using the 'Go' buttons. At the beginning of the uploading photo process, a continuous form, Auto-Upload Photos will list all the photo file names currently existing in the CIMS database. Click button 'Go' on the form to start uploading photos. The matched photo will be embedded to its corresponding record in the CIMS observation table. For unmatched names, users can either search another folder or manually insert the photos later from the data review/edit forms.

8. **Compact and Save the uploaded database.** Once all the Culvert information for a contract have been uploaded into the CIMS, click on the 'Compact DB' button to save the converted database into a specified location and click the 'Close' button.

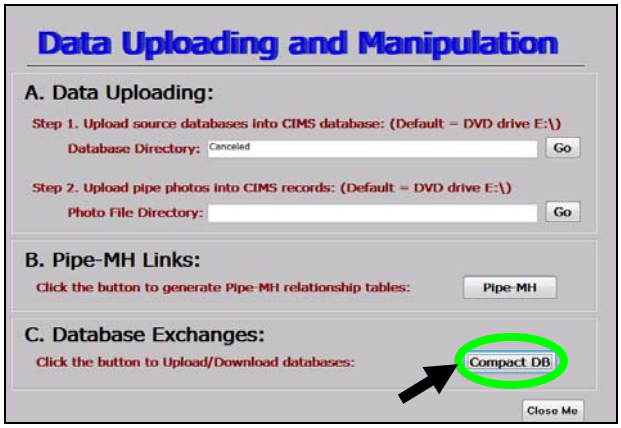


Figure 8 - Saving converted database file

Upon completion of uploading all DVD data, the Straight Line Diagrams (SLD) database will be updated for use as a visual check for determining accuracy of matched culvert inspections. With the provided data, the NJIT research team was

able to match and plot 840 out of a total of 6,255 culvert inspections from NMWCC to their respective inlets/outlet with lat/long coordinates, as seen in some of the sample SLD data plots below. Figure 9 shows the NJ map displaying the routes surveyed by the contracts and details the areas where plots were either verified to be good or needed re-checking.

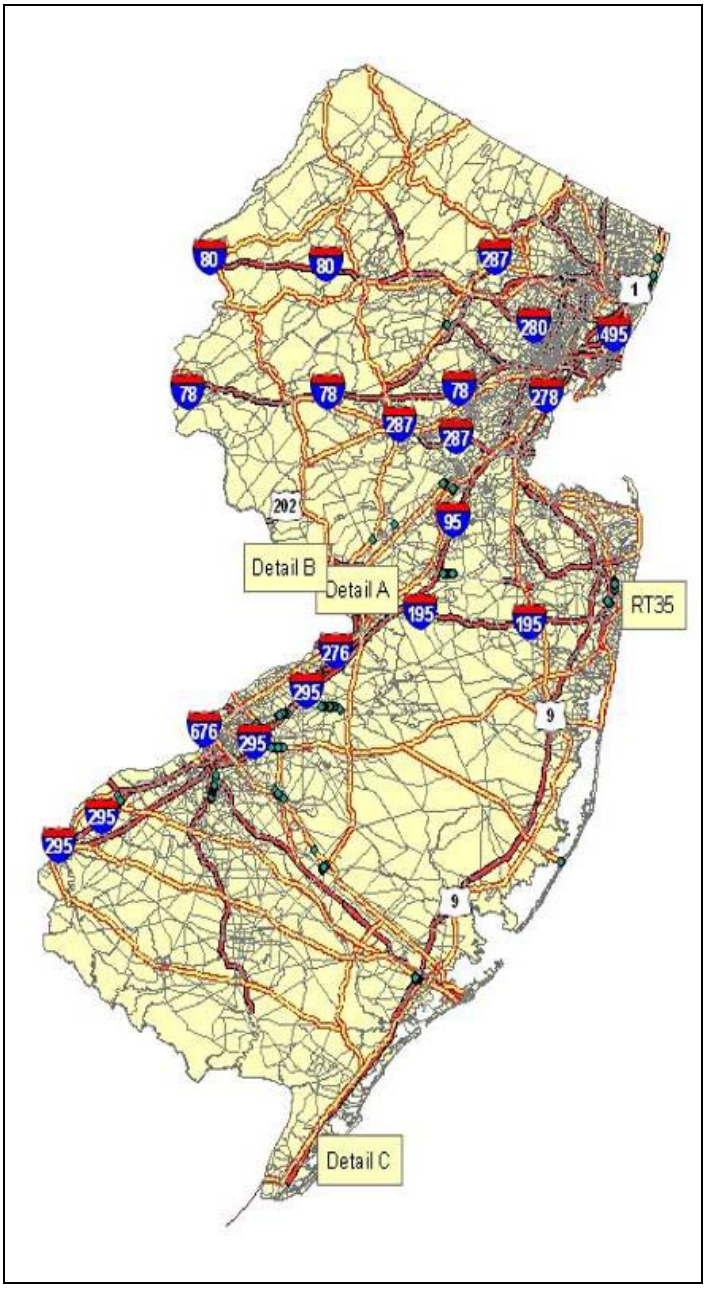


Figure 9 - Pipe Inspections Locale – NJ state routes and locations of detail plots

Figures 10, 11, and 12 show “accurate” plots of data points in the database (e.g., on RT35). Inlets and outlets (represented by green nodes) are connected by culverts (represented by blue poly lines) on the maps.

Figure 10 - Route 35 Sample A

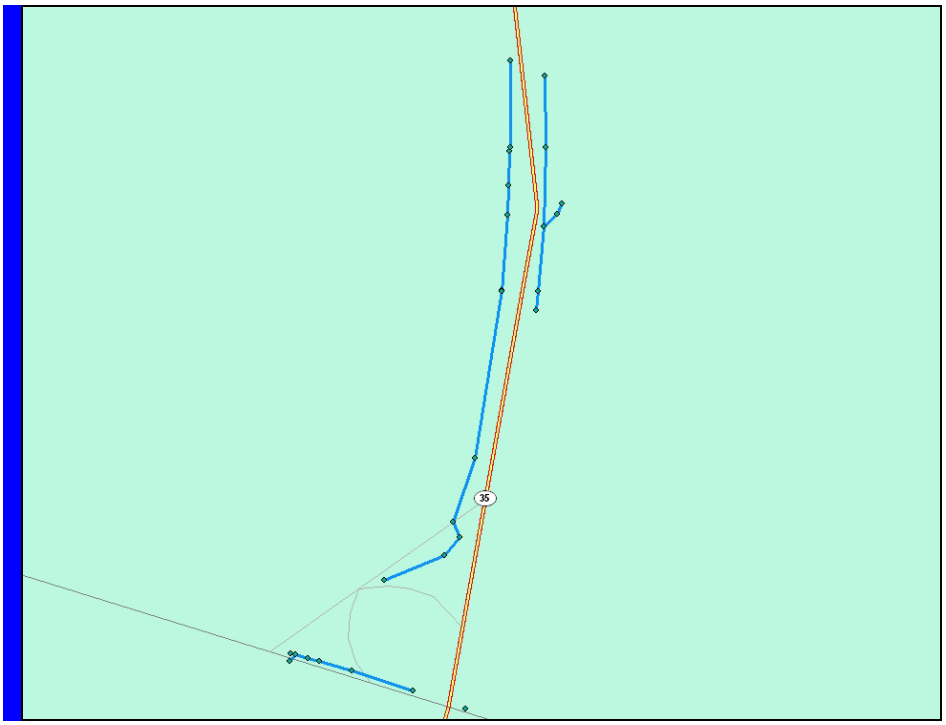


Figure 11 - Route 35 Sample B

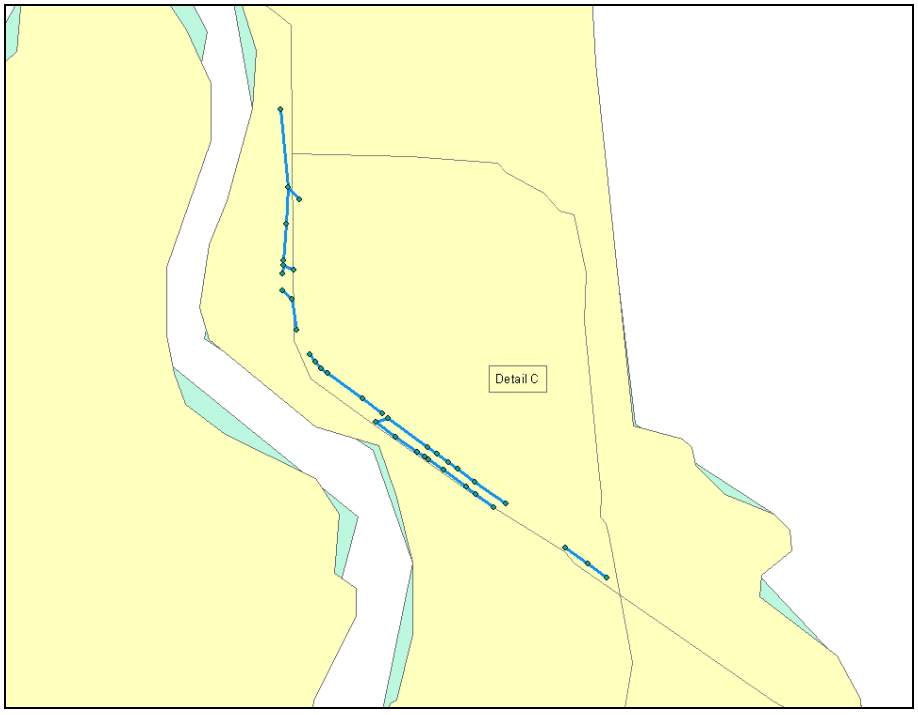


Figure 12 – Cape May Sample

Figures 13 and 14 show irregular plots containing pipes which overlap or have multiple connections and require further verification of the locations of the inlets/outlets (e.g., in Detail A and Detail B pictures).

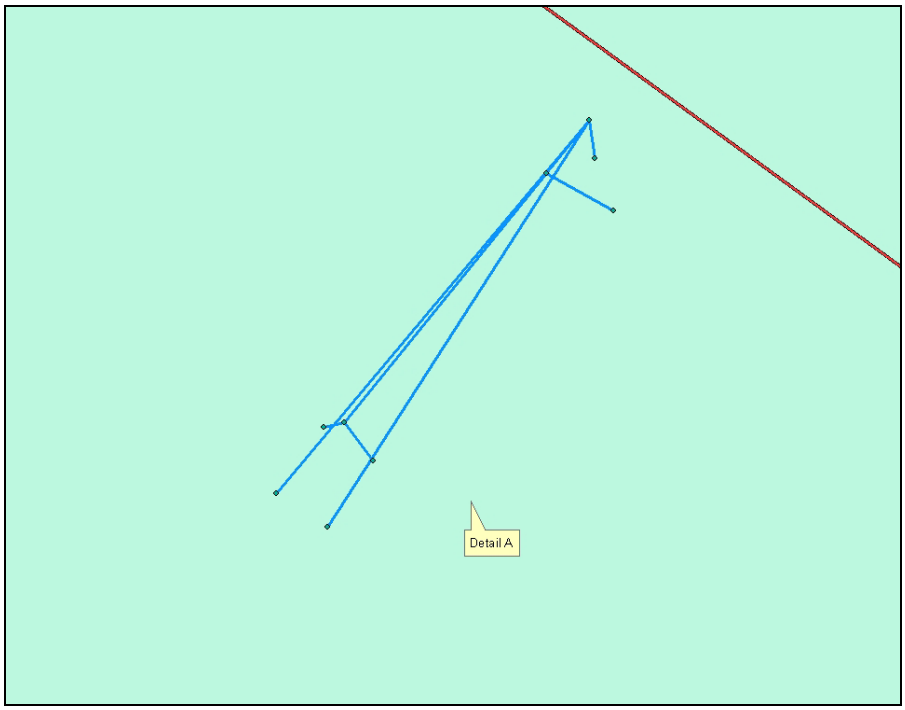


Figure 13 – Detail A: Irregular pipe connections

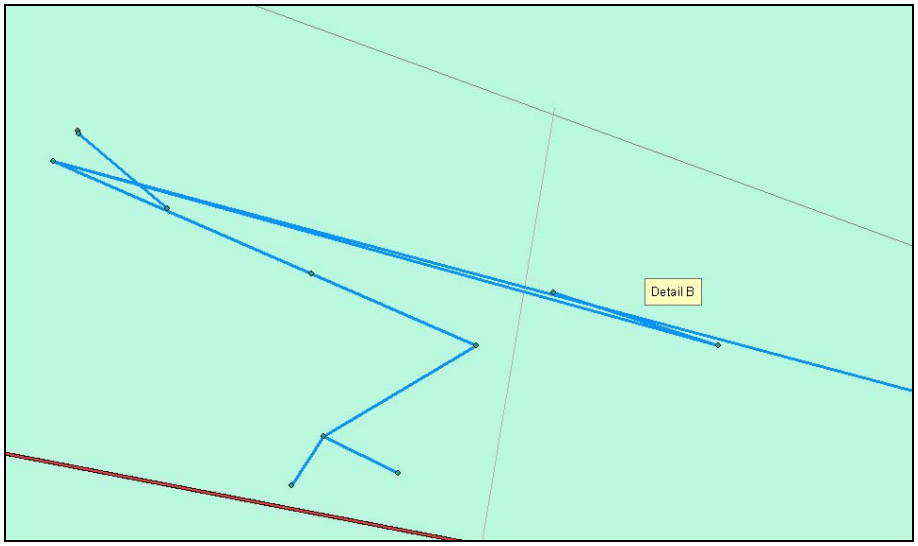


Figure 14 – Detail B: Irregular pipe connections

Using the uploaded culvert data, a query was created to match culverts to their respective inlets and outlets to create a summary containing latitude and longitude information for the pipe inspections as seen in the sample table below, Table 2 - Matched Pipe Inspections Summary. The ability of the procedure to yield the expected results was based upon reported data; nevertheless, the demonstration model worked optimally.

Table 2 - Matched Pipe Inspections Summary – NWMCC Sample

Pipe ID	-105-124	-106-125	-1-1	-11-11	-115-135
Street	RT33W	RT33W	RT.91	RT.91	RT33E
City	NEPTUNE N.J.	NEPTUNE N.J.	FRANKLIN,NJ	FRANKLIN,NJ	NEPTUNE N.J.
Location_code	HIGHWAY	HIGHWAY	STATE ROUTE	STATE ROUTE	HIGHWAY
Type	CONCRETE	CONCRETE	CAST IRON	CONCRETE	CONCRETE
Diameter	18 in /	15 in /	30 in /	36 in /	15 in /
Asset Length	298.7	15.8	58.1	198.2	21.3
Surveyed Length	298.7	15.8	58.1	198.2	21.3
Condition_number	0	0	0	0	0
Use_of_sewer	STORMWATER	STORMWATER	STORMWATER	STORMWATER	STORMWATER
Inspection_reason	REHABILITATION INSPECTION	REHABILITATION INSPECTION	REHABILITATION INSPECTION	REHABILITATION INSPECTION	REHABILITATION INSPECTION
Start_Node_ID	mh40.70w	mh40.70w	HW0.68n	mho.40s	cb40.41e
Start_Node_Loc	RT33W	RT33W	RT.91	RT.91	RT33E
Start_Node_Lat	40.20655761	40.20655761	40.46004705	40.45791963	40.20639742
Start_Node_Long	-74.04844031	-74.04844031	-74.48414392	-74.48519225	-74.05407227
Start_Node_Type	Manhole	Manhole	Headwall	Catch Basin	Catch Basin
Start_Node_MP	40.7	40.7	0.68	0.4	40.41
End_Node_ID	mh40.66w	cb40.70w	cb0.67s	mh0.44s	cb40.40e
End_Node_Loc	RT33W	RT33W	RT.91	RT.91	RT33E
End_Node_Lat	40.20644669	40.20655818	40.45997027	40.45844279	40.20639665
End_Node_Long	-74.04955635	-74.048429	-74.48434249	-74.4849951	-74.05413967
End_Node_Type	Manhole	Catch Basin	Catch Basin	Catch Basin	Catch Basin
End_Node_MP	40.66	40.7	0.67	0.44	40.4

Table 2 shows a summary of five pipe inspections (ID's: -105-214, -106-125, -1-1, -11-11, and -115-135) used in the straight line diagram plotting. Based upon the lat/long coordinates of the starting and ending structures for each inspection,

points were created for each set of inlets/outlet structures and plotted on a NJ base map. Those points were then connected to represent a pipe connection.

The summarized information listed the street and city location, type, diameter, asset length (actual length), and surveyed length of the pipes inspections. The Start_Node_ID and End_Node_ID represented the name given to the inlet and outlet structures with its locations given by the Start_Node_Loc and End_Node_Loc fields. The Node_Type field describes the type of inlet/outlet structure (ex. Manhole, Catch Basin). The Node_MP field gives the mile post location along a specified route where the inlets and outlets were surveyed.

Table 3 - Matched Pipe Inspections Summary - CIMS Database

Vendors	da_pipe	da_pipe_struct	MH_Pipe_List with Lat/Long
MOUNT	2,317	3,190	3,003
COOK	804	951	273
NWMCC (old)	6,711	6,527	1,007
TOTAL uploaded	**9,832**	**10,668**	**4,283**

Table 3 provides a summary of the current inventory in the CIMS database, which is installed on NJDOT computers. The da_pipe field contains the number of culvert records and the da_pipe_struct contains the number of inlets/outlets from each vendor. The MH_Pipe_List field lists the number of inlet/outlets inspections with latitude and longitude coordinates, which is extracted and given to NJDOT to update SLD database. Currently, all data supplied by MOUNT and COOK have been uploaded to CIMS. The total uploaded data from NWMCC include 6,711 culverts, 6,527 inlet/outlets and 6,975 matched inspections. As of December 2009, more DVDs have been submitted by NWMCC however, they do not contain coordinate data. Hence NJIT returned those DVDs to NJDOT requesting vendor to correct the data as per the specification and resubmission for acceptance.

In summary, about 94% of culvert structures (3,003 out of a total of 3,190) for MOUNT contain the latitude and longitude coordinates. For COOK, 29% of the culvert structures (273 out of a total 951) contain the latitude and longitude coordinates. The remaining 71% of the COOK database were from previous years' inspections where coordinates were not provided. As of the August 2009 inspections, COOK has supplied the necessary GPS coordinates in the DVDs. For NWMCC, 15% of the culvert structures (1,007 out of a total 6,527) contain the latitude and longitude coordinates. NWMCC provided 5,390 culvert structures with latitude and longitude coordinates in a separate database but without route information. NJIT plotted that information as shown in Figures 10-14 and identified 1,007 culvert structures with latitude and longitude coordinates.

Task 1.2: Customize CIMS to Generate Quarterly Reports to NJDOT Upper Management

For demonstration purpose, CIMS II developed a Sequential Query Language (SQL) statement builder form. It allows the user to choose which records to display in a summary report. Click 'Summary Reports' button from CIMS main switch form (see Figure 2) to open the SQL statement builder form (Figure 15).

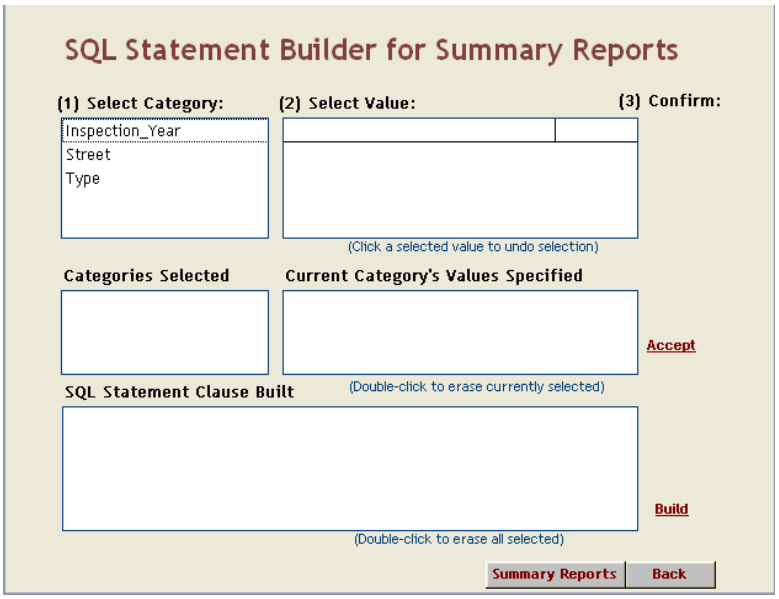


Figure 15 – SQL Statement Builder Form

User will create a customized data query in three simple steps:

Step (1) Select Category – choose query criterion one at a time, such as 'Type', 'Street' (i.e., Route #), and 'Inspection_Year' as examples. The category list can be expanded as customer requests.

Step (2) Select Values – from the value list box, select category value(s). When user selects a category, the value list box will automatically display the category's available values (See Figure 16).

Step (3) Confirm Selections – there are two actions to be taken in this step (See Figure 17):

- Click 'Accept' to confirm current selected values for the chosen category. After accepting currently selected value(s), user can either continue to choose next category and its value(s) or re-select other value(s) for currently chosen category. The re-selected value(s) can replace the previously selected value(s) by user decisions. The multiple selected categories will have 'AND' logic relationship and the multiple selected

values within each category group will have 'OR' logic relationships (e.g., SQL statement clause in Figure 17).

- When finished making all selections, click 'Build' to generate a SQL statement clause as a data filter that will be used by customized summary reports in their data sources.

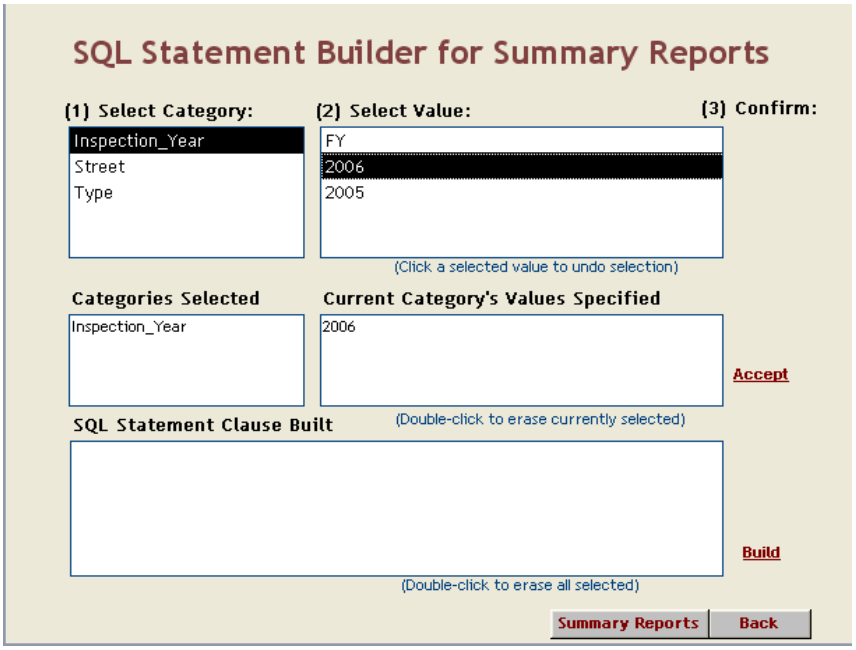


Figure 16 – Select Category and its Value(s)

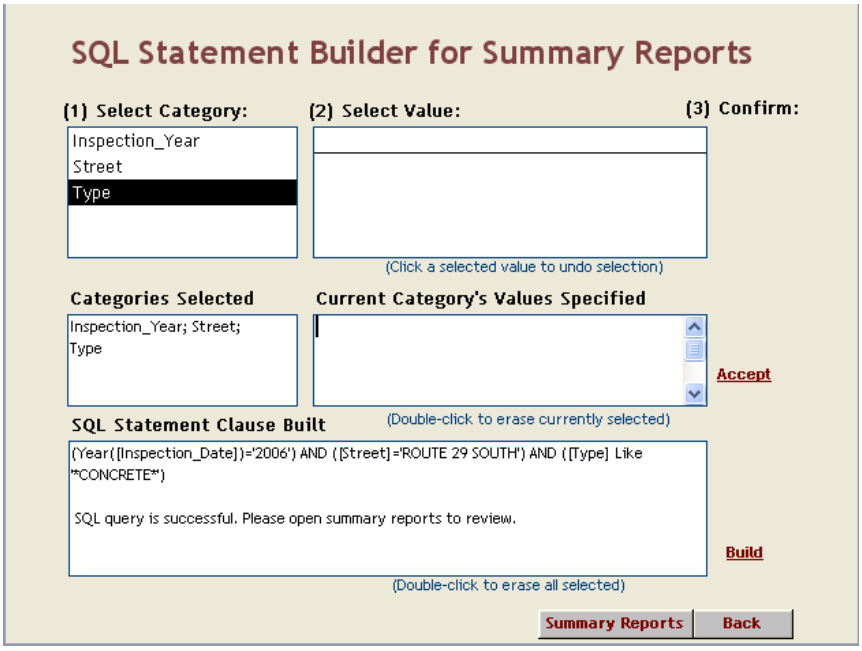
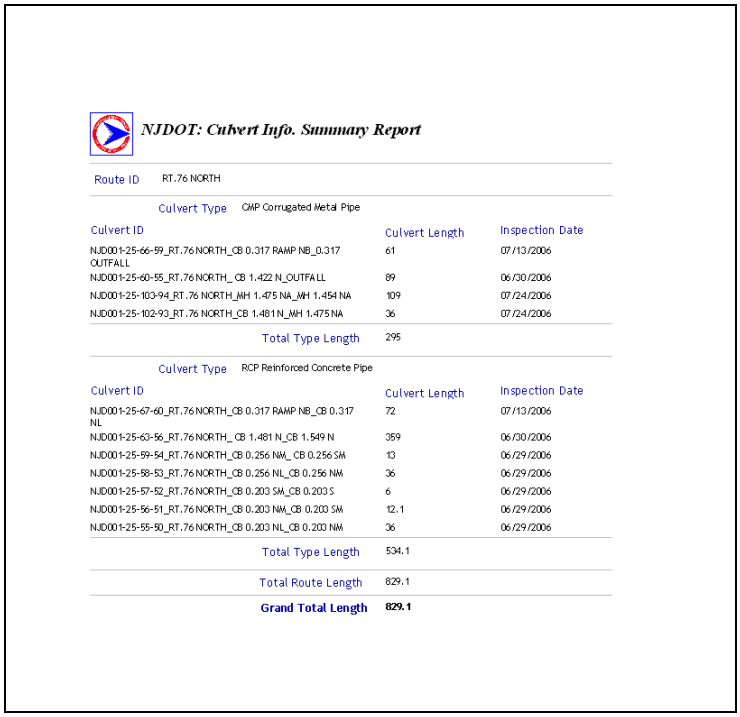


Figure 17 – Confirm Selections

After successfully generating a SQL statement, click button 'Summary Reports' on the builder form to open a report that displays the querying result based on current CIMS database tables. The fields displayed are selected for demonstration purpose only.



NJDOT: Culvert Info. Summary Report

Route ID RT..76 NORTH

Culvert Type CMP Corrugated Metal Pipe

Culvert ID	Culvert Length	Inspection Date
NJD001-25-66-59_RT.76 NORTH_CB 0.317 RAMP NB_0.317 OUTFALL	61	07/13/2006
NJD001-25-60-55_RT.76 NORTH_ CB 1.422 N_OUTFALL	89	06/30/2006
NJD001-25-103-94_RT..76 NORTH_MH 1.475 NA_MH 1.454 NA	109	07/24/2006
NJD001-25-102-93_RT..76 NORTH_CB 1.481 N_MH 1.475 NA	36	07/24/2006
Total Type Length	295	

Culvert Type RCP Reinforced Concrete Pipe

Culvert ID	Culvert Length	Inspection Date
NJD001-25-67-60_RT.76 NORTH_CB 0.317 RAMP NB_CB 0.317 NL	72	07/13/2006
NJD001-25-63-56_RT.76 NORTH_ CB 1.481 N_CB 1.549 N	359	06/30/2006
NJD001-25-59-54_RT.76 NORTH_CB 0.256 NM_ CB 0.256 SM	13	06/29/2006
NJD001-25-58-53_RT.76 NORTH_CB 0.256 NL_CB 0.256 NM	36	06/29/2006
NJD001-25-57-52_RT.76 NORTH_CB 0.203 SM_CB 0.203 S	6	06/29/2006
NJD001-25-56-51_RT.76 NORTH_CB 0.203 NM_CB 0.203 SM	12.1	06/29/2006
NJD001-25-55-50_RT.76 NORTH_CB 0.203 NL_CB 0.203 NM	36	06/29/2006
Total Type Length	534.1	
Total Route Length	829.1	
Grand Total Length	**829.1**	

Figure 18 - Summary Report.

The SQL builder querying results can be used to create a variety of customized summary reports. NJIT research team suggests that after all available data sets have been migrated to an Oracle database, the SQL builder form and its functionality be enhanced and more summary reports can be developed based on customers' requests.

Task 1.3: Develop a Data Translation Program to Populate the CIMS for COBRA and Other Inspection Systems

In Phase II, CIMS needs to populate its data database with data records from multiple vendors. Since inspection vendors (NWMCC, COOK, and MOUNT) used different data structures to store their records, CIMS required to development of several individual transfer procedures to manipulate the data uploading processes with respect to each vendor's data sources. Table 4 provides a summary of the data formats as provided by the vendors. Since there is such a wide variation in vendor data, during the data manipulation, CIMS will auto-detect the data source internal structure and determine which set of queries should be used to select, summarize, and re-organize vendor's data records so as to insert the qualified records into the CIMS data database tables.

Currently, the CIMS application is capable of translating all three vendors' data sets through the developed data transfer procedures. However, the following issues are still remaining to be solved:

- Inspection contractors should provide NJDOT with organized Access database records as defined by current contract specifications (specs). Only the data provided by NWMCC were compatible with the specs formats.

- Most of the vendors' data sets were missing latitudinal and longitudinal information for the inlets and outlets. Without these coordinates, CIMS cannot generate mapping data sets for the straight line diagram database.

- All of the vendors' data sets were missing pipe inspection condition information in the records. It is critical to have the condition rating to determine the present value of the entities and to determine the proper maintenance treatment techniques.

- Data integrity problems were caused by vendors using different formats to define key identifiers in their data tables (such as Pipe id and Inlet/Outlet id). They typically named the same entity with different identifiers. Some of the Inlet/Outlet identifiers do not contain route related information. Thus, the same structure (as indicated by its milepost) may be incorrectly indicated to lie on several different routes. Subsequently, records for these structures will not be linked to their relevant pipe segment records. Sometimes, there are data inconsistencies even within the same vendor's records, such as, missing dimensional column data, extra spaces in entries (e.g., 'CB-6.949 N' vs. 'CB-6.949N'), and mismatched identification (e.g., 'ccb 18' vs. 'CB 18.226 E'). These inconsistencies have compromised the data integrity of the CIMS databases, and result in duplicate counts of entities, as well as missing records in matching tables.

- At the present time, CIMS does not have input/upload capability for Outfall structure information. The NJIT team has designed and installed a data entry form for NJDOT to enter outfall records. It is expected that this functionality will be incorporated into CIMS in the next phase of the CIMS development.

The NJIT team strongly recommends that vendors must provide inspection data in the specified formats and guarantee the data accuracy when they deliver the DVDs. An auto-detect program could be developed to check the completeness of the data and verify if the data are consistent with current NJDOT specs. Thus, NJDOT may reject unqualified data sets immediately if the checking results are not acceptable. In order to unify the pipe and structure naming convention, the NJIT team suggests that NJDOT provide a list of standardized identifiers for entities (Inlet/Outlet) for all vendors to use.

Table 4 - Summary of Data provided by Contractors

NWMCC - 11 tables, 6 required	**MOUNT** - 44 tables, 12 tables required	**COOK** - 23 tables, 5 required
MH_DEF	_FIELD_DEFS	AI_T
MH_T	_HASH	AIC_T
MHE_T	_OBJECT_TYPES	C_T
MHO_T	AdjacentPipeInfo	DC_T
MHUS_T	ArcGISImport	DR_T
O_T	ArcGISNetwork	M_T
OG_T	Asset	MHUS_T
P_T	Code	N_T
S_T	CodeCategory	NC_T
Sat_S_T	CodesGroup	NE_T
Sat_T	CodeSystem	NF_T
	CodeSystemScoringIndex	NI_T
	DB_VERSION_STAMP	NO_T
	DBHistory	P_T
	InspectionRating	PD_T
	Lateral	R_T
	LateralInspection	RSN_T
	LateralObservation	S_T
	LateralObservation_Photos	SF_T
	MainInclinationSurvey	SI_T
	Manhole	SO_T
	Manhole_Assets	TE_T
	MediaCatalog	V_T
	MHInspection	
	MHInspection_Photos	
	MHObservation	
	MHObservation_Photos	
	Note	
	Observation	
	Observation_Photos	
	ObservationRating	
	Photo	
	Project	
	SamplesFile	
	SealGroutInsp	
	Sealing	
	Sealing_Photos	
	Setting	
	TVInspection	
	TVInspection_Ratings	
	Unit	
	UnitClass	
	UnitSystem	
	VideoMedia	

As per NJDOT specifications, inspection vendors are required to provide NJDOT with Access files containing culvert data organized according to the current NJDOT specs. Only the Access files provided by NWMCC were compatible for testing with the requested format. Hence, NJIT developed a data translation program to convert the data tables from MOUNT Construction and COOK (as listed in Table 2). Currently, the CIMS system is capable of translating data tables from all three contractors through the uploading procedure. The data generated from the uploading of the Culvert Inspection Data are converted into data tables listed in Table 5.

Table 5 - CIMS Standard Data Identifiers

da_pipe
da_pipe_struct
tbl_Pipe_MH_list
tblCulvert_Assessment
tblCulvert_Assessment_JobDone
tblCulvert_Assessment_UserCost
tblCulvert_ILP_Model_Input_Data
tblCulvert_ILP_Model_Input_Groups
tblCulvert_ILP_Model_solutions
tblCulvert_Optimal_Solutions
tblCulvert_Treatment_Action_code
tblCulvert_Treatment_Action_Decision
tblCulvert_Treatment_Alternatives
tblCulvert_Treatment_Policy
tblCulvert_Water_Discharge
tblDrain_to_Waterway
tblGraph_Structure_KeyWords
tblGrate_type
tblHeadwall_Type
tblJoint_Types
tblJustify_actions
tblMatched_Pipe_MH_in_CurrentDB
tblMilepost_List
tblPhsical_Observations
tblPipe_Conditions
tblPipe_Materials
tblPipe_Shapes
tblStructure_Conditions
tblVideo_Observations
tblVideo_Observations_Updated
tblVidio_Directions
tblWaterway_tied_to

For the MOUNT database, differences in the supplied data required additional modifications to the CIMS uploading algorithm in order to import the data from the DVDs. The dvd inventory for MOUNT is listed in Table 6.

Table 6 - Mount Construction – DVD Inventory

DVD Name	GPS Data
1. Rt. 1 - Edison	Yes
2. Rt. 1 - North Brunswick	Yes
3. Rt. 1 - South Brunswick MP 15 - 16	Yes
4. Rt. 1 - South Brunswick MP 16 - 17	Yes
5. Rt. 9	Yes
6. Rt. 9 - Woodbridge	Yes
7. Rt. 18 - Colts Neck	No
8. Rt. 18 - East Brunswick	Yes
9. Rt. 18 - East Brunswick	Yes
10. Rt. 22 - Bridgewater	Yes
11. Rt. 27 - Highland Park	Yes
12. Rt. 29 - Trenton	Yes
13. Rt. 31 - Trenton	Yes
14. Rt. 31 - West Amwell	Yes
15. Rt. 33 - Hightstown	Yes
16. Rt. 35 - Berkley Twp	Yes
17. Rt. 35 - Brick Twp	Yes
18. Rt. 35 - DP08405 NJDOT Drainage Restoration Central	Yes
19. Rt. 35 - Perth Amboy	Yes
20. Rt. 35 - Red Bank	Yes
21. Rt. 35 - Shrewsbury	Yes
22. Rt. 36 - Hazlet	Yes
23. Rt. 36 - Long Branch	Yes
24. Rt. 37	No
25. Rt. 37 - Berkley Twp	Yes
26. Rt. 66 - NJDOT511	Yes
27. Rt. 71 - Allenhurst	Yes
28. Rt. 91 - North Brunswick	Yes
29. Rt. 130 - Cranbury	Yes
30. Rt. 130 - Robbinsville	Yes
31. Rt. 130 - South Brunswick	Yes
32. Rt. 184 - Woodbridge	Yes
33. Rt. 202 - West Amwell	Yes
34. Rt. 202 - West Amwell	Yes
35. Rt. 206 - Hamilton	Yes
36. Rt. 440 - Woodbridge	Yes

The DVDs that contain some or all latitude and longitude coordinate data are designated as having GPS data, however, most databases are not 100% complete for all inlets/outlets surveyed on the route due to unknown manholes, outfalls, buried manholes, etc.. Two DVDs (Rt. 18 – Colts Neck and Rt. 37) do not contain any coordinates for inlets/outlets. All records have been uploaded to the CIMS database regardless of missing Lat/Long coordinates, which can be added once information is supplied.

Similarly, the inspection data provided by COOK also required its own specific uploading parameters (See Access tables). The modified CIMS application is now currently capable of importing and converting those COOK inspection data, which contain the necessary information.

Table 7 - COOK – DVD Inventory

1. NJ DOT Central October 2008	Uploaded to CIMS database
2. NJ DOT Central September 2008	
3. NJ DOT North October 2008	
4. NJ DOT North September 2008	
5. NJDOT August 2009	Uploaded to CIMS database, Lat/Long supplied
6. NJDOT September 2009	
7. NJDOT October 2009	
8. NJ DOT Route 166	Uploaded to CIMS database
9. NJ DOT Route 35	
10. NJ DOT Route 37	
11. NJ DOT Route 46	
12. NJ DOT Route 9	

For the NWMCC database, no latitudinal and longitudinal coordinates were associated with the inlets and outlets. Therefore, it was necessary to create a procedure to match up the NWMCC inlet/outlet inspection identification codes with a separate Global Positioning Satellites (GPS) survey data, known as the TREE table, which consisted of surveyed inlet/outlet coordinates. The TREE tables were subsequently obtained from NWMCC by NJIT. The TREE table data are extracted by using the GPS Pathfinder Office Software Kit. The GPS Pathfinder Office software exports the data to a Goegraphic Information System (GIS) mapping program and extracts the TREE data into Access database files for use in the CIMS system.

These problems of crucial missing and/or irregular information should be addressed with the potential contractors to avoid future inconsistencies. The current problems are being addressed by careful, time-consuming data cleansing processes in order to generate useable results.

Task 1.4: Conduct a Survey of All the Old Inspection Contracts and Provide Cost and Time Estimate to Update and Upload That Data to CIMS

Currently, there are over 1,050 Video Home System (VHS) tapes containing old inspection data. The contents of these tapes document the condition states of inspected culverts, which date back as far as 1998. In that regard, it is most likely that these pipes have deteriorated since their last inspection. In addition, it is also very likely that the more problematic sections of the sewer system may have had multiple inspections during this time frame. The multi-inspection data sets need to be quantified in a consistent manner to assign a condition number to the individual pipe sections. However, firstly, the pipe sections need to be identified in the database. Secondly, the video footage and condition states must be linked to the database. To accomplish this task, the VHS tapes must be digitized.

The task of digitizing the VHS tapes may be performed by an external contractor. We have located all the VHS tapes packed in boxes and stored in closets onsite at the NJDOT main office. The VHS originals appear to be in good condition, and there are no duplicates, as far as we can tell from this inventory search. However, the quality of the digital file extracted from the VHS tapes was considerably less than the digitally recorded files stored on the DVDs.

The digitizing task requires that the VHS tapes be converted into DVDs with condition states assigned and finally uploading that information into the CIMS database in the same manner accomplished with the current DVD inventory. There are several ways to convert the analog video signal from the VHS tape to a digital DVD format using:

1. A video capture card that records (captures) and converts (digitizes) the video with the option for video editing, or

2. A video capture without editing capabilities.

Table 8 lists the costs and time estimates for digitizing the VHS tapes without editing by various suppliers.

Table 8 - Cost and Time Estimate for Tape Digitizing

Supplier	Cost Estimate	Time Estimate
Colonial TV & Appliance	$15/tape	4 weeks to delivery
GRG LLC	$9.5/tape	4 weeks to delivery
NJIT Multimedia	$30/tape	n/a (too large a job for current staff)

The task of digitizing the VHS tapes is also important, since it will allow for automatic quantitative and qualitative assessment of condition states. The condition state will form a basis for cost estimation and culvert stability and maintenance cycles. In addition, this task will compile a listing of all cleaning and

repair/replacement contracts. This data will be helpful to decide to remove inspection tapes of culverts which were replaced. The rating of the condition of each culvert in the system, ultimately, will help predict future conditions and facilitate the timely repair of deteriorated culverts, and thus avoid expensive failures.

The rating of the condition of each culvert in the system is based on a performance model for each culvert type as well as the date of installation. In general, several parameters that describe the condition of an existing culvert can be quantified in terms of potential predictors of the overall culvert condition. These parameters are recorded at various culverts distributed geographically throughout New Jersey. A mathematical model is used to evaluate the statistical significance of the parameters. The results are then used to classify a culvert according to its condition ranking, in which the highest number is the worst condition, and the lowest number indicates the best condition. There are several methods (objective and subjective) that can be used to quantify the parameters of the model that specifies the condition states of culverts.

One subjective method would be to individually view the videos, either during the digitizing process or afterwards. The drawback of viewing the videos during digitizing process is that playback is not allowed. Hence, this method is left for the expert pipe assessor. An alternative is to train an individual to view the tapes and assign condition states while liberally using the playback option. This method requires sufficient time for personnel training on a variety of general pipe inspection results.

An objective method of assigning condition states includes automated computer modeling such as filtering and edge matching. Details of this method are provided in our recommendations in the following section.

Task 1.5: Migrate to Oracle

Due to the capacity limit of Access databases, currently NJDOT contractors' inspection records have to be uploaded into multiple Access databases in CIMS. The NJIT research team has investigated the feasibility of converting all the uploaded Access databases into an Oracle database so that all pipe and structure data records can be contained in one place. This consolidation will greatly facilitate the data query and statistical analysis of CIMS records. Also, it will simplify the implementation, testing, and maintenance of a large scale statewide CIMS system in the future.

The NJIT research team selected Oracle Database 10g Express Edition (Oracle Database XE) as the testing database. Oracle Database 10g is a small scale database that can be installed on any size host machine with any number of Central Processing Unit (CPUs) (one database per machine). Oracle XE will store up to 4GB of user data, use up to 1GB of memory, and use one CPU on

the host machine. For demonstration purposes, the Oracle database 10g was installed on NJIT Telus-National.org IIS server machine. Using Oracle SQL Developer 2.1, several sample Access database tables (e.g., pipe inspection table and manhole structure table) have been migrated into the Oracle 10g database successfully.

In future implementation, a large scale Oracle database (Oracle 9i) will be installed on a designated application server at NJDOT. This machine should hold both the Oracle 9i database server and an IIS server. The IIS server is required to run a browser-based file uploading website. This website will allow NJDOT contractors to submit their pipe/structure inspection Access databases online (see Task 1.6 for details). And the CIMS Oracle 9i database will integrate these submitted inspection records so that the website users can quickly summarize all historical inspection and financial information to generate customized reports.

As far as further improvement, the NJIT research team suggests a re-design of the CIMS interfaces and data queries with a Visual Basic platform to use the Oracle 9i as the back-end database for the CIMS application in the future. Thus, the capacity limit of Access database will be avoided and the resulting faster response time will improve CIMS performance.

Task 1.6: Develop Web Application for Inspection Database Online Submission

As requested by the NJDOT pipe/structure inspection contractors, NJIT research team has developed a browser-based pure Active Server pages (ASP) web application for contractors to submit their pipe/structure inspection databases online (see Figure 19).

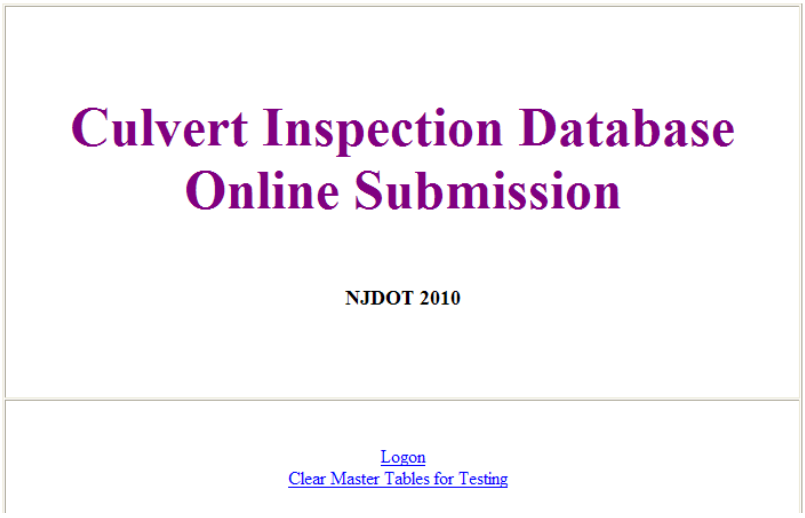


Figure 19 - CIMS Online Submission Home Page

This web application will allow the contractors to select their pipe/structure inspection databases (.mdb file) on local machines and upload the selected files through the Internet onto the hard drive of an NJDOT designated application server (i.e., the IIS/Oracle database machine mentioned in Task 1.5). Then, the application will systematically check if the submitted data comply with pre-specified data integrity test criteria (e.g., if the recorded latitude/longitude values for manholes go beyond the boundaries of the physical areas under consideration). If the data set passed the exam, the application will allow the user to append the data set into the CIMS Oracle database. Otherwise, an error found message will displayed and request contractors to modify their data and re-submit again later.

There are three major steps in using the application:
Firstly, users need to login to the application with an assigned Contractor ID, User ID, and Password so as to protect data and system safety (See **Error! Reference source not found.**).

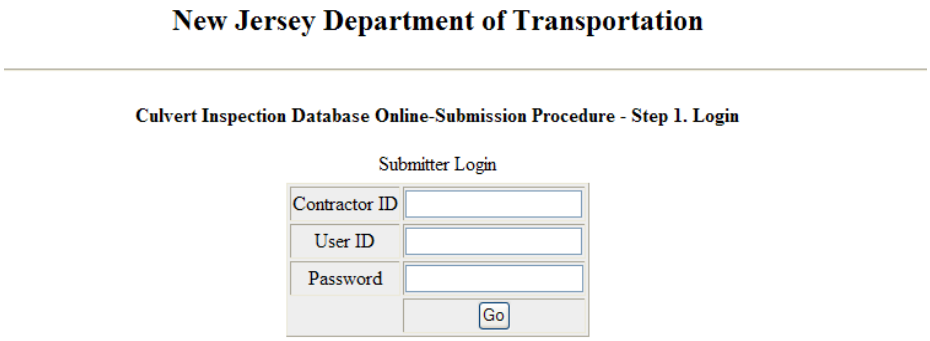


Figure 20 - Login Page

Secondly, users must specify the full path of submitting database (See **Error! Reference source not found.**). This database must be a qualified Access database with pipe, manhole, and inspection observation tables in it.

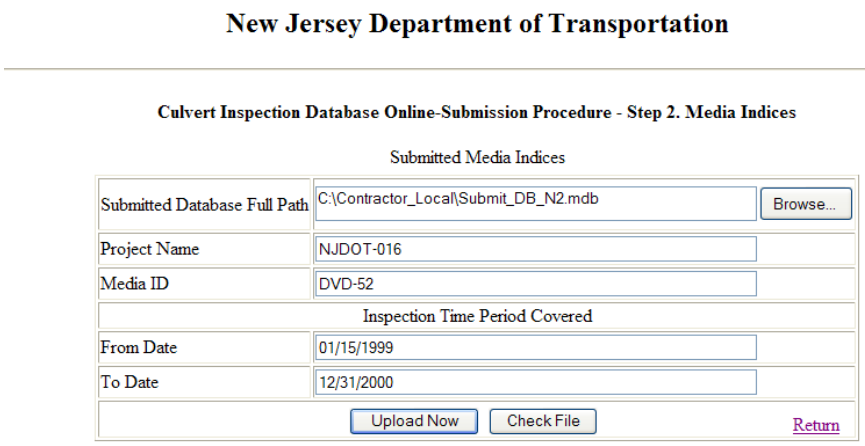


Figure 21 - Uploading Files

Click the 'Upload Now' button to copy the database onto the NJDOT application server's hard drive. When the file uploading process is successful, users will get a prompt at the bottom of the uploading form that displays the uploaded file name and binary size (See **Error! Reference source not found.**).

In this step, the data uploading form also allows users to enter more media index information to help CIMS management to clarify the data sources, such as the project name, Media ID, and Inspection date period. These data entries can be used for data quality control and to facilitate the data retrieval processes.

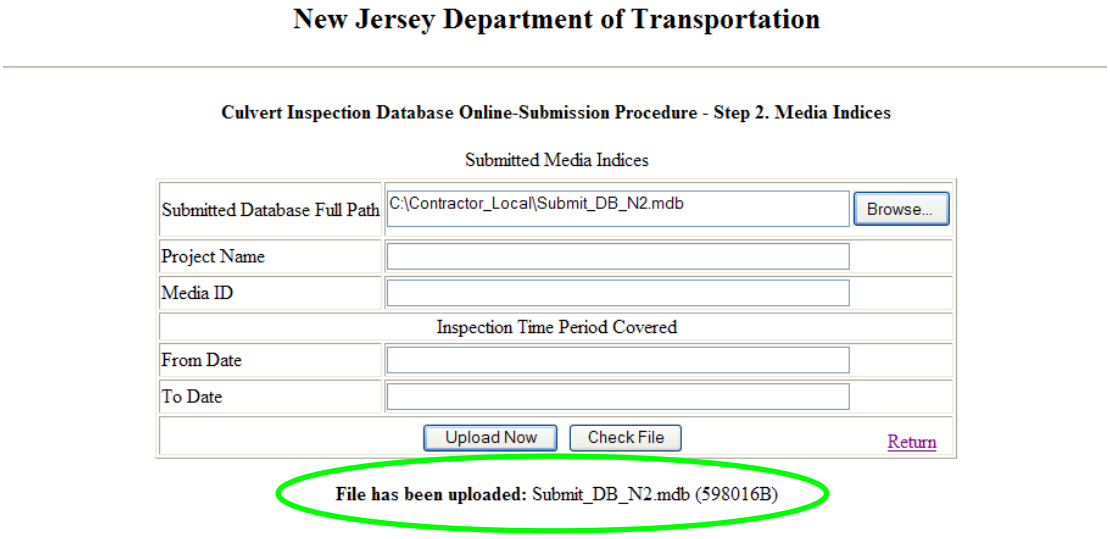
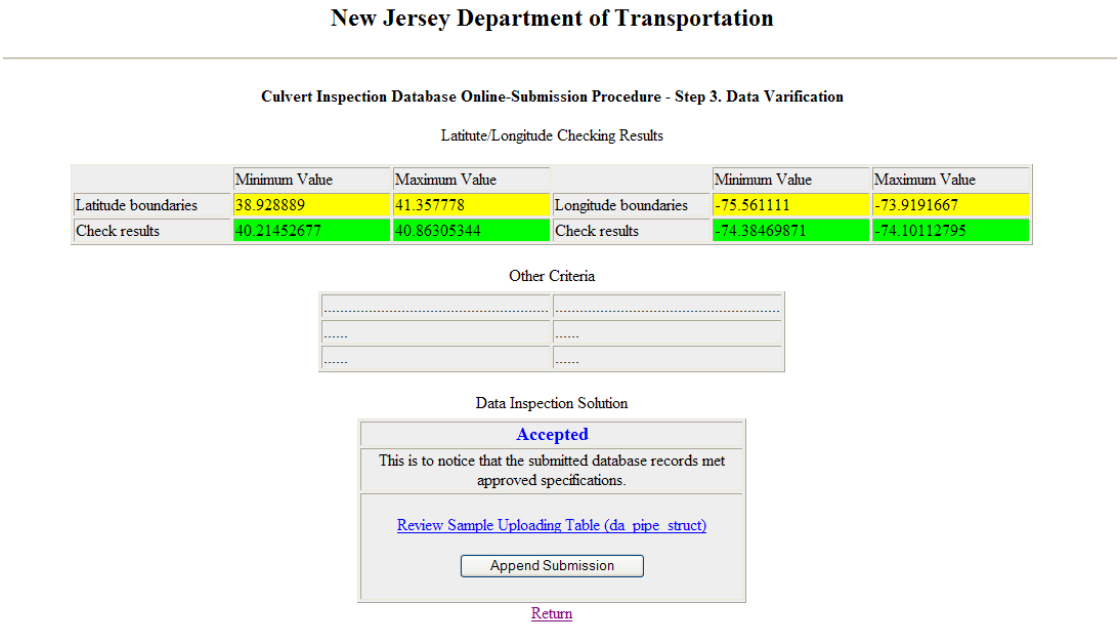


Figure 22 - Uploading File Page

After receiving the feedback file name prompt, click the 'Check File' button to go to the last step: Data Submission Verification.

Thirdly, the web application will systematically check if the submitted data comply with pre-specified data integrity test criteria. The checked results will be displayed as groups of comparison tables that show the valid data sets in green and invalid data sets in red, respectively (See Figure 23 and 25).



New Jersey Department of Transportation

Culvert Inspection Database Online-Submission Procedure - Step 3. Data Varification

Latitute/Longitude Checking Results

	Minimum Value	Maximum Value		Minimum Value	Maximum Value
Latitude boundaries	38.928889	41.357778	Longitude boundaries	-75.561111	-73.9191667
Check results	40.21452677	40.86305344	Check results	-74.38469871	-74.10112795

Other Criteria

.....	.....
.....	.....
.....	.....

Data Inspection Solution

Accepted

This is to notice that the submitted database records met approved specifications.

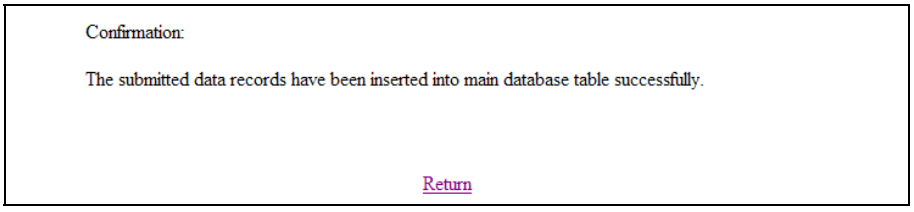
Review Sample Uploading Table (da_pipe_struct)

Append Submission

Return

Figure 23 - Checked Data Page

If the submitted database is accepted, Users can click the 'Append Submissions' button to insert qualified data set into CIMS Oracle database. If the insertion is successful, a confirmation page will be displayed to notify users (See **Error! Reference source not found.**).



Confirmation:

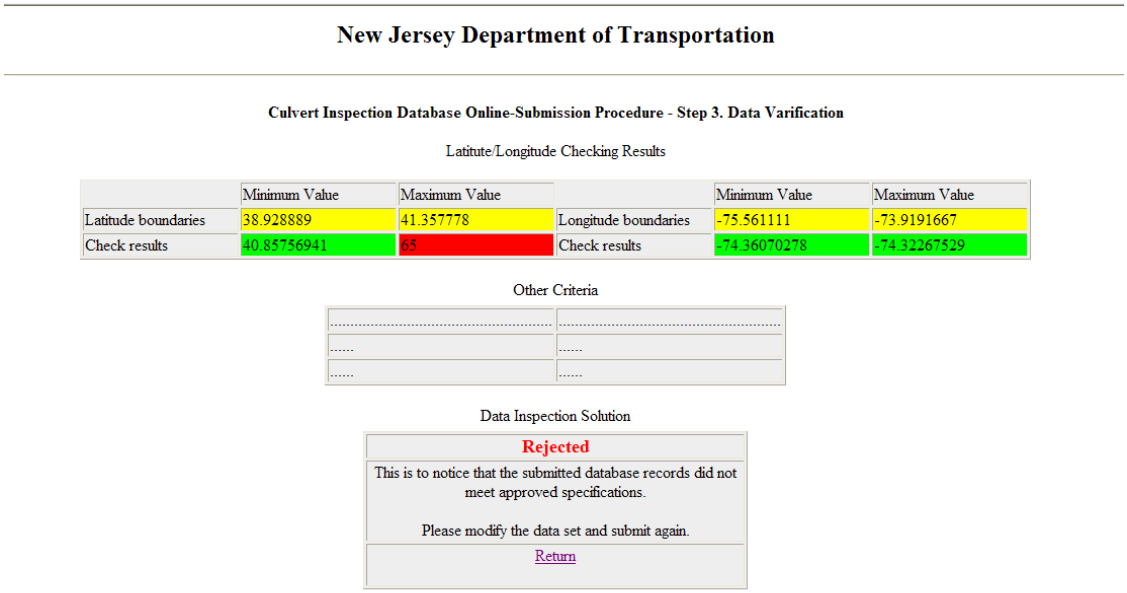
The submitted data records have been inserted into main database table successfully.

Return

Figure 24 - Acceptance Message Page

On the other hand, if any of the data integrity tests failed, the data inspection solution box will show 'Rejected' signal (See **Error! Reference source not found.**). The contractor will need to modify the data sets as needed and submit again.

At present, this application is a demo version only. It is limited to uploading qualified Access pipe/structure inspection databases. If required, it can be easily modified to upload Word, PDF, and Excel documents online, too. The application could also automatically insert relevant information into different NJDOT databases as per user requests.



New Jersey Department of Transportation

Culvert Inspection Database Online-Submission Procedure - Step 3. Data Varification

Latitute/Longitude Checking Results

	Minimum Value	Maximum Value		Minimum Value	Maximum Value
Latitude boundaries	38.928889	41.357778	Longitude boundaries	-75.561111	-73.9191667
Check results	40.85756941	65	Check results	-74.36070278	-74.32267529

Other Criteria

.....	.....
.....	.....
.....	.....

Data Inspection Solution

Rejected

This is to notice that the submitted database records did not meet approved specifications.

Please modify the data set and submit again.

Return

Figure 25 - Rejected Message Page

This browser-based contractor inspection database uploading web application will improve communications between NJDOT and its contractors, shorten the contractors' data submission time, and provide the potential for other types of online file delivery.

FUTURE RECOMMENDATIONS AND CONSIDERATIONS

Risk Analysis

Further additions to be included in future phases of the Culvert Information Management System would be to incorporate a risk analysis protocol through the use of available CIMS data as well as a video sequencing technique. A feasible method to determine the risks associated with the existing pipe infrastructure would be to assess the locations of the culverts and inlets/outlets based on GIS coordinates with respect to the centerlines of NJ roadways. As such, a pipe traversing a route or highway would be ranked with higher priority with regards to inspections and other considerations if failure were to occur.

Automatic Pipe Condition Assessment using Video Sequencing

For future considerations, assessing pipe conditions can be done through an automated process through the use of video sequencing to determine current condition states (CS). The main idea is to use the correlative properties of consecutive video frames for optimal adaptive correlation filtering and for comparison of the spectral content of multi-resolution wavelets of consecutive video frames.

The following steps outline the proposed methods for the assessment:

Step 1: Normalize each frame starting with the pipe beginning frame as the reference (Preprocessing will include correction for image distortions, etc.).

Step 2: Apply Gabor wavelet or Bi-harmonic spline wavelet.

Step 3: Compare spectral content at each resolution (detail) level with the reference frame and then apply correlation filter on each consecutive frame using the reference frame as a base model.

Step 4: Assign a condition number [1-5] based on the filter outputs (condition number: 5 = repairs are urgent; 1 = Pipe is perfect).

Outfall Records

Outfall information plus the quantity and quality of flowing water and sediments is required by the NJDEP for NJDOT to comply with storm water regulations. Hence, including additional outfall records into CIMS is a much needed enhancement. NJIT has already developed a data entry form for NJDOT to input the outfall data records, which is to be incorporated into CIMS.

Financial Analysis

The ultimate use of CIMS is to maintain and/or improve the current condition state of all culverts in the system. Optimization routines were already included in CIMS, but we performed a limited analysis based on financial information of only

eight original jobs provided by NJDOT. Hence, in order to complete the evaluation of the fullest potential of CIMS, NJIT needs additional financial information for all of the culverts in the system.

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