TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-93/1440-1F		

4. Title and Subtitle	5. Report Date
APPLICATIONS OF ROBOTICS AND OTHER AUTOMATED TECHNIQUES TO THE CONSTRUCTION, MAINTENANCE, AND INSPECTION OF HIGHWAY SYSTEMS	November 1993
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Walter W. Boles, Donald A. Maxwell, Philip D. Heermann (Sandia National Laboratories), Wesley D. Scott, Robert W. Adams, Connie J. Flickinger, Richard M. Gallegos, and John A. Mannering	Research Report 1440-1F
9. Performing Organization Name and Address	10. Work Unit No.
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	11. Contract or Grant No. Study no. 2-10-93-1440
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas Department of Transportation Office of Research and Technology Transfer P.O. Box 5051 Austin, Texas 78763	Final: May - August 1993
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Study Title: APPLICATIONS OF ROBOTICS AND OTHER AUTOMATED TECHNIQUES TO THE CONSTRUCTION, MAINTENANCE, AND INSPECTION OF HIGHWAY SYSTEMS

16. Abstract

Many tasks in the construction, maintenance, and inspection of highway systems are dangerous, repetitive, and labor intensive. Mitigation of hazards to human workers, while performing this type of work, is expensive and inefficient. In cases such as these, application of robotics technologies has the potential for improving some of the Department's operations. Advanced robotics technologies exist in other disciplines such as manufacturing, defense, energy, and space-related industries. These technologies, however, are not extensively applied to highway-related construction, maintenance, and inspection tasks. The objective of this study was to begin a systematic, cooperative effort to apply advanced robotics technologies to highway-related problems. An implementation model was developed which provides a systematic process leading to implementation. The study was limited to a list of seven potential problem areas selected by TxDOT management--flagging for traffic control, culvert clean-out and inspection, drilled shaft inspection, placement and retrieval of traffic cones, non-destructive testing of roadway density during construction, underwater inspection for scour and deterioration, and traffic signal and illumination bulb replacement. The study included field visits, interviews, telephone interviews with officials from the other 49 states, and literature review. Sandia National Laboratories' Robotic Vehicle Range contributed to the technology assessment portion of this study.

17. Key Words	18. Distribution Statement
Robotic, Automation, Construction, Maintenance, Inspection, Highway	No Restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	216	

Form DOT F 1700.7 (8-69)

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Research Study Number 0-1440

Sponsored by
Texas Department of Transportation

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

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IMPLEMENTATION STATEMENT

This research identified forty-seven potential areas where automated or robotic technology could be applied to the Department's operations. Seven of these areas were selected for further evaluation during the summer of 1993. Some of the remaining areas are felt to merit further investigation for future studies. This report contains specific recommendations for the seven applications.

The study also identified a research and development process leading to implementation of advanced automation and robotics technologies into the Department's operations. The process is designed to reduce the risk and the cost associated with the development and implementation of these technologies. The implementation process is recommended as one that the Department may wish to utilize in the pursuit of advanced technologies applicable to the Department's operations. The study found no evidence to reject the proposed research and the development process leading to implementation.

No specifications or standards or new materials were developed. No new equipment was developed. Studies for the development of new equipment, however, are recommended.

Potential benefits resulting from the implementation of advanced automation technologies include: savings in construction and maintenance cost, enhanced performance of Department personnel, and increased safety to both the motoring public and Department personnel. Specific benefits can be determined during the next phase of research.

The next phase of research, which addresses the additional steps required for implementation of new equipment and methods, includes detailed feasibility studies, pathfinder development, prototype development, manufacturing, and training.

DISCLAIMER

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SUMMARY

The first objective of this study was to identify areas where there is a potential for the application of advanced automation and robotics technologies to the Department's construction and maintenance operations. The second was to investigate seven selected application areas to establish the feasibility for further study of those areas. An analysis framework, leading from concept initiation to final implementation, was developed in response to the need to finally implement any technologies developed as a result of Departmental research. This analysis model consists of the following phases:

1. Identification of Potential Application Areas and Alternative Approaches
2. Subjective Filters -- Screen Out Infeasible Applications
3. Objective Filters -- Screen Out Uneconomic Applications
4. Pathfinder Development and Laboratory Testing
5. Prototype Development and Field Testing
6. Manufacturing, Training, and Field Implementation

This study presents the results of phase 1. and phase 2. of the process for the following seven selected application areas. The study was conducted during from May 1993 through August 1993 and reflects the circumstances existent at that time.

Flagging for traffic control: The automation of existing flagging techniques is more of a human behavior problem than it is a technology problem. In short, based upon a nation-wide telephone survey, simply automating existing operations does not seem to be very productive. Although a few applications have had some local success, no system has gained any degree of wide acceptance. While some improvements to existing methods can occur, entirely new approaches should be explored. For example, an in-vehicle alarm to alert drivers of changing conditions would be a possible new approach. Systems such as this may prove more effective than simply automating certain aspects of existing methods.

Culvert Clean Out and Inspection: Study results show that culvert clean-out is a regional problem rather than a state-wide problem. However, it is a serious problem in those regions most affected. Some Department personnel state that culvert cleaning is expensive and only occurs when there are no other options such as clearing drainage ditches and allowing natural water flow to clean the culvert. Methods using high-pressure water and a vacuum truck are in limited use. Additional research is needed to identify more economical and simple methods. Inspection of new culverts is of some concern as is the fact that existing culverts can not be inspected until they are cleaned out.

Drilled Shaft Inspection: Study results show that field personnel tend to feel that the existing visual methods are adequate for their purposes. On the other hand, management and design personnel expressed the opinion that design assumptions are based upon performance criteria that must be verified by the inspection process. Therefore, they expressed the strong opinion that better inspection is needed, especially for slurry holes. Technology is available to

dimensionally map drilled shafts and provide a permanent record of the dimensions, even in slurry holes. Work should proceed to develop economical inspection devices that meet engineering design requirements and the operational requirements of field inspection personnel.

Placement and Retrieval of Traffic Cones: Study results indicate that automation of this activity is economically feasible only in those instances where it represents a major portion of the work day in high-density traffic areas. Two existing machines were identified from a literature search. One, in use in Japan, is fully automated during both placement and retrieval. The other one, made in the United States, requires two workers to handle the cones in addition to requiring a driver for the vehicle. Additional study is required to develop conceptual designs and perform economic feasibility studies before hardware development should proceed. The number of machines needed must be determined before adequate feasibility studies can be accomplished.

Non-Destructive Testing of Roadway Density During Construction: During the study, this problem evolved into two separate issues -- determination of density of sub-base material, base material, and asphalt pavements and measuring the thickness of concrete and asphalt pavements. Existing nuclear testing is considered adequate by most field personnel for measuring the density of base materials. However, more coverage (profile data information) and less time consuming methods are desired. Ground penetrating radar technology has potential for performing this test. Additional research is required to verify the effectiveness of this technology.

The existing method of drilling cores in new concrete pavements to determine thickness is costly and time consuming. Less costly and higher coverage methods are needed. Research has been conducted to verify that ground penetrating radar will work for this application. Limitations include fresh concrete (less than approximately two months old) and pavements over about 10 to 12 inches (25.4 to 30.48 centimeters) thick. Different radar frequencies can potentially solve the depth problem but more research will be required before this technology is ready for implementation.

Underwater Inspection for Scour and Corrosion: Some field personnel feel that current inspection methods using human divers are sufficient. Some engineering design and management personnel would like to have more detailed data. Technology is available to increase the fidelity and coverage of these inspections. Remote visual inspection can be performed using existing remotely controlled submersible vehicles except in high velocity water conditions. Other sensor modalities will likely provide more-detailed information, especially in low visibility situations. Further research is required to determine desired data measurements and methods of obtaining the data from appropriate sensor technologies. Additional research is also required to determine appropriate modifications to existing remotely controlled equipment for use in high velocity conditions.

Traffic Signal and Luminaire Replacement: The importance of this task varies from district to district. Rural districts generally are not interested since they have few bulbs to replace. It is a very important problem in urban districts. The magnitude of this problem may be much greater than evidenced in this study since much of this work is done by power companies and cities and is not the responsibility of the State. It is believed that automating this task is not technically feasible at this point in time. Moving the light source to a more convenient location and using optical fiber to transmit the light to the signal head is suggested for further research.

INTRODUCTION

Background

The construction, maintenance and inspection (CMI) of highway systems involves many tasks which are dangerous or labor intensive. The application of robotics techniques or automation to those tasks has the potential for improving productivity, or reducing costs, by removing humans from danger areas and reducing the amount of human labor required to perform a given task. The slip-form concrete pavement machine is an example of past efforts in automation.

Advanced robotics technologies have been developed in other disciplines such as manufacturing, defense, energy and space-related industries. These technologies have not been widely applied to highway-related construction, maintenance, or inspection tasks.

The construction robot requirements for mobility and adaptation to an uncontrolled environment present a fundamentally different problem than the requirements of the stationary manufacturing robot in a controlled factory. Because the environment can be defined for a stationary robot, it is possible to preprogram the required responses. The construction robot cannot be preprogrammed with an exact response because the results of any robotics action will vary with time as the conditions surrounding it change.

The first step in implementing robotics techniques for the CMI of highway facilities is to identify problems that are important to the management and central design staff of the highway department, the field personnel, and the public as well as those that are technically feasible to accomplish. This is a problem-to-solution approach rather than a solution-to-problem approach. Figure 1 is a conceptual representation of all possible problems where robotics techniques could be applied (represented by the rectangle). The three circles represent the three groups that should be involved in the successful implementation of an automated solution.

Successful implementation of automated solutions can only occur for problems common to all three circles. This is represented by the shaded region in Figure 1. The rationale for this concept is that management controls resources for development efforts, engineering design can place more stringent requirements on field forces for increased inspection fidelity and accuracy, any devices or procedures developed must be acceptable to field forces and the public, and the technology must be available to accomplish the task. Additionally, engineering management can enforce methods and procedures that increase safety and/or economic utilization or resources.

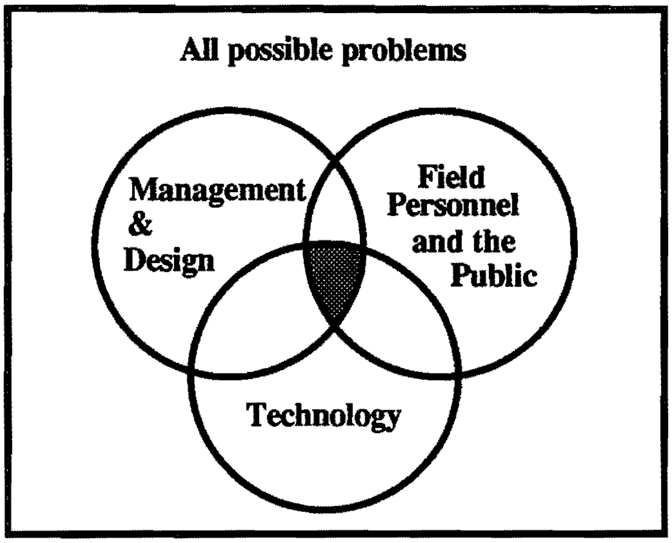

Figure 1. Possible Problems

Since one of management's concerns is the economical utilization of resources, efforts to utilize technology developed in other fields should demonstrate a systematic process of technology transfer that reduces the risk associated with applications development. The process should also exhibit a clear path to eventual implementation for attractive applications. This realization lead the study team to develop a process model that consists of the following phases:

1. Identification of potential applications
2. Subjective filters (select mutually important applications)
3. Objective filters (conceptual designs and economic feasibility studies)
4. Pathfinder development and laboratory testing
5. Prototype development and field testing
6. Manufacturing, training, and field implementation

This process can be viewed as a filtering process where each successive phase is more rigorous than the previous and eliminates some applications from further consideration. Each successive phase also requires more resources to accomplish. The goal of the process is to reduce the cost and risk associated with technology transfer and applications development. This represents an efficient method of development because the majority of available resources can be expended on the more promising applications while unpromising applications can be eliminated without investing substantial effort and resources.

The identification of potential applications is a crucial phase. The search must be very broad and is heavily dependent upon the Departments' personnel to use their expertise to identify important problems. This phase is exploratory and contains no quantitative measures.

The subjective filter phase consists of interviews and discussions with experts from the three circles represented in Figure 1. The importance of each application to each group is assessed as well as the technical feasibility. This phase emphasizes building a consensus among the three groups on the importance of the applications being investigated. No quantitative measures are examined.

The objective filters phase consists of a conceptual design(s) of the pathfinder, technical, and economic feasibility studies. Conceptual designs must exist before performance parameters can be estimated and feasibility studies accomplished. This phase is quantitative.

The pathfinder development and testing phase consists of designing and building a laboratory test platform where candidate technologies can be compared. This phase is where technology options are investigated, for incorporation into the prototype, and performance estimates from the previous phase are adjusted to experimental results.

The prototype development and testing phase consists of building and testing the prototype device. Lessons learned from the pathfinder phase are incorporated into the prototype. Field testing is conducted to verify performance measures.

Applications that successfully pass each of the previous phases are then ready for design enhancements and manufacturing. Training of field personnel and field implementation can then be accomplished.

Objectives

This study is concerned with phases one and two as described in the previous section. The objective of the study is to identify several problems in the CMI of highway systems which could be improved by implementing robotic techniques. These problems are then subjected to the subjective filters phase to determine if any merit further investigation in phase three--the objective filters phase.

After identifying potential problems, preliminary feasibility assessments were performed by consultation with appropriate experts. Problems which required significant technological breakthroughs or which were judged too broad in scope were to be eliminated at this stage to avoid unproductive expenditures of resources.

To reduce the development costs of the prototype hardware, other industries were examined to determine if any equipment could be adapted to the selected problems of interest. The emphasis is upon technology transfer. Leveraging existing technology in the defense, energy, space, and manufacturing industries is a priority.

Scope

The scope of this study was limited to identifying problems that are suitable for investment in feasibility studies and development of pathfinder or prototype equipment. No hardware development was included. The length of the study was limited to four months (May - August 1993).

STUDY ORGANIZATION

Research Personnel

Primary research responsibility was assigned to the Construction Automation and Robotics Laboratory (CARL) at Texas A&M University. The principal investigators were Walter Boles and Don Maxwell. Assistance was provided by undergraduate and graduate research assistants. Sandia National Laboratories assisted in the assessment of potential robotics technologies and is responsible for the section titled "Sandia National Laboratories Assessments of Tasks."

Texas Department of Transportation (TxDOT)

A working group consisting of TxDOT personnel provided input to generate the initial problem set. An advisory committee of executive management personnel reviewed the problem set generated by the working group and defined the scope of the study.

Work Plan

The project consisted of developing a large array of possible problems and then reducing this array to the few problems that could be addressed within the study period. Seven problem areas were selected for study in this project. The study tasks were as follows:

Task 1:	Identify a Preliminary List of Applications
Task 2:	Assemble a Working Group and an Advisory Committee
Task 3:	Convene Advisory Committee and Refine the Application List
Task 4:	Assess Operational Issues for Selected Applications
Task 5:	Convene Advisory Committee and Review Assessments
Task 6:	Assess Robotics Issues for Selected Applications
Task 7:	Develop Recommendations and Final Report

STUDY PROGRESSION

Application List Development and Refinement

An initial list of problems where automation research related to CMI of highways was presented along with the research proposal. This list was used as a starting point for the discussions of the Working Group meeting held 21 May 1993 in Austin, Texas. These discussions led to a "long list" consisting of 47 potential problems. A short list of 17 priority items was selected from the long list to narrow the scope of the study. Minutes of the meeting are in Appendix B.

CARL staff reviewed the 17 potential application areas and categorized them into three groups based upon the degree of difficulty of implementing an automated solution to the problem. The categorized list was presented to the advisory committee (see Appendix C).

The Advisory Committee met on 18 June 1993 to review the "short list" as categorized by the CARL staff. Minutes of the meeting are in Appendix C. This meeting resulted in a "working list" of seven problem areas which were to be evaluated further. These problem areas are:

Area 1: Flagging for Traffic Control
Area 2: Culvert Clean Out and Inspection
Area 3: Drilled Shaft Inspection (and Measurement)
Area 4: Placement (and Retrieval) of Traffic Cones
Area 5: Non-Destructive Testing of Roadway Density During Construction
Area 6: Underwater Structure Inspection for Scour and Corrosion
Area 7: Luminaire and Traffic Signal Bulb Replacement

Application Assessments

Field experts were interviewed to determine the important operational issues associated with each of the seven working areas. The important issues were defined as the purpose of the operation (what exactly was to be accomplished), the scope of the operation, and any constraints on the operation. These application assessments were forwarded to Sandia National Laboratories for their use in assessing the automation potential of the seven working areas.

During the interview process general descriptions of the work were developed based on the following algorithm for any task: 1) Arrive at site; 2) Deploy work equipment; 3) Work (complete the task that was to be accomplished); 4) Recover work equipment and restore site; 5) Depart from site. The use of an automated system implies that a change in work equipment will occur. This change may require new vehicles for transportation, or have shorter or longer equipment set-up and recovery times, thereby affecting more than just the actual task to which the automated system is applied. Logistical problems associated with tools and supplies must also be addressed.

Appendix D contains the application assessments which were forwarded to Sandia National Laboratories accompanied by the general work descriptions developed during the interview process.

Field Interview Summary Results

Interviews with area/resident engineers and maintenance supervisors were conducted to determine their need for a solution to the seven working problems. A list of the personnel contacted and copies of the interviews are in Appendix E. These results are based upon the opinions of the individuals interviewed. Individuals may have different perspectives based upon their personal experience. Larger surveys should be conducted to determine the state-wide demand for potential products when economic feasibility studies are conducted.

Flagging for Traffic Control

Area engineers were receptive to the idea of using portable traffic lights to control traffic flow in areas of construction or maintenance. One area engineer was aware of an experiment using a mannequin which failed because the mannequin was kidnapped within three days and never returned. He did not want a mannequin-like device because the citizens of that area were likely to shoot at it. He was afraid that once they started shooting at mannequins they would then shoot at highway workers.

Generally, maintenance personnel did not approve of an automated system for flagging. They did not believe they could trust the device as they could a fellow worker.

Culvert Clean Out and Inspection

Automating culvert inspection was not considered very important. The ability to see through a culvert was, in general, considered adequate. A small robotic device which has a video capability to allow inspection of culverts too small for a man to enter was of some interest and would likely be used if available.

Culvert cleaning was of more importance than inspection. Several area engineers expressed the desire for some type of equipment to allow them to clean culverts. One stated that contractors bid a very high price to clean the existing culvert when they were adding an extension. Another engineer stated only 15 percent of the culverts in his area were large enough to allow a man to enter them to clean them out manually.

Drilled Shaft Inspection (and Measurement)

Drilled shaft inspection is typically performed by engineering staff. The current visual examination technique, which uses a mirror to shine sunlight down the hole, was considered to be adequate by many field personnel contacted. Some interest in a portable light with or without a video camera was exhibited.

Placement (and Retrieval) of Traffic Cones

Interest in an automated traffic cone system varied with the level of traffic on the roads. Rural areas had no interest because they could set cones in the time periods when no traffic was present. Maintenance personnel in high traffic areas did not like setting traffic cones manually from a truck or trailer because of the potential for being hit by passing vehicles.

Non-Destructive Testing of Roadway Materials During Construction

The radioactive nuclear density gauges were thought to be adequate. The only desirable improvements mentioned were a reduction in time required to take a data point and an increase in the frequency of testing. When use of ground-penetrating radar was suggested, the area engineers did not believe the workload of an area would justify the device. They thought it might be useful at the district level.

Underwater Structure Inspection for Scour and Corrosion

Essentially no interest in underwater inspection techniques existed at the area level, since a specialized team located at the state headquarters did all underwater inspections.

The specialized underwater inspection team believed underwater visual inspection could be automated using a remotely-controlled submersible. The point was made that the time required to perform an inspection was critical because of the number of bridges requiring inspection. Any automated technique should not require more time to perform an inspection than was currently required using divers, or it would only be used in an exceptional situation (e.g. when the current was too strong for a diver, or debris around the bridge made diving unsafe).

Luminaire and Traffic Signal Bulb Replacement

This task was not considered very important by districts that have a small volume of this work. Signal light bulb replacement did not generate a large workload in these mostly rural districts and was not considered particularly hazardous. In more urban districts, however, the problem was considered more serious due to the increased work load and the heavier traffic conditions. Other entities are usually responsible for this work in cities.

Other Texas Interests

Field personnel expressed interest in problems which were not on the working list of seven items (they were on the long list, however). These areas included: 1) slow moving work zone safety; 2) intersection lettering and stripe painting; 3) replacement/repair of crash attenuators (limited to urban areas); 4) a robotic surveyor for use on roadway centerlines; and 5) installation of reflective buttons on the roadway centerline.

State CMI Automation Efforts

Telephone interviews were conducted with representatives of the other 49 Departments of Transportation. Complete data for Alaska and Hawaii were not compiled. The information available for Alaska includes only non-destructive testing of roadway density and underwater structure inspection. Data for Hawaii includes only underwater structure inspection. Names of the manufacturers contacted are contained in Appendix G. The current practices of the states are summarized by working area below. Applications of automated or robotic techniques are notably rare. The techniques being used are summarized in Table 1.

Flagging for Traffic Control

New York and Oklahoma were the only states which used automated devices other than a portable traffic signal. The New York device, known as a robostop, was a tripod mounted, paddle which was operated by remote control. Oklahoma occasionally used message boards accompanied by dummy flagmen.

Jim Kellenberger, Traffic Control Project Engineer, North Carolina, stated North Carolina was trying to replace flaggers with portable traffic signs even in short-term construction. North Carolina uses warning signs, message boards and arrow boards in addition to flaggers using either standard paddles or flags.

Minnesota is experimenting with using fewer people in the work zone by using mechanical-portable signs, warning zones, off-duty police officers and portable speed bumps.

The standard paddle sign was the flagging method of choice. Only two states did not use the paddles signs: Rhode Island, which used flags only, and Massachusetts, which used state troopers because of union issues. Arkansas used the paddles in a limited manner relying mainly on flags. Indiana, Nevada and Maine were considering using the newer SHRP (Strategic Highway Research Program) paddles which have a strobe light which can be activated to attract the motorists attention.

Table 1. Summary of State Techniques

Task	Technique Used	State(s)
Flagging for Traffic Control	Paddles	28
	Flags	Rhode Island
	Combination	14
	Contracted	Alabama, Utah, Massachusetts (state troopers)
	Robostop (tripod mounted paddle)	New York
Culvert Clean-out	Manual and/or high pressure water	43
	Hydraulic culvert opener and excavator	Arkansas, New Jersey
	High pressure steamer	Minnesota, Wisconsin
Culvert Inspection	Visual	44
	Video equipment	Georgia, Iowa, California

Table 1 Summary of State Techniques (continued)

Task	Technique Used	State(s)
Drilled Shaft Inspection	No inspection	22
	Lower man down	11
	Visual from surface	5
	Contracted out	6
	Pilings only, no shafts	Maine, Vermont, Idaho
	Video equipment	Florida, South Carolina
	Gamma ray testing	Arizona
	Sonic logging	Arizona, Washington (once)
Placement of Traffic Cones	Men on back of trucks	39
	Modified truck	Arizona, California
	Cone Wheel	Nebraska, Nevada, New York, Oklahoma, North Carolina, Ohio
Non-destructive Testing of Roadway Density	Nuclear density gauges	35
	Nuclear density gauges and cores	6
	Sonic testing	Georgia
	Falling Weight Deflectometer	Kentucky, Mississippi, Nebraska, Rhode Island, South Dakota
	Cores only	North Dakota
Underwater Structure Inspection - Scour and Corrosion	In-house divers	17
	Contracted divers	15
	Combination of In-house and Contracted divers	14
	Inspection not done	New Mexico, Arizona, Nevada
	Video equipment	Michigan, North Carolina, Oregon, Utah, Florida
	Still pictures	California, Rhode Island, Massachusetts, North Carolina
	Sonar	Illinois, Iowa
	Fish Finder	Utah, California
Traffic Signal and Luminaire Bulb Replacement	Manual	47

Culvert Clean Out and Inspection

The main culvert cleaning technique was manual cleaning assisted by high pressure water. Alternative methods were: a hydraulic culvert opener and excavator, Arkansas and New Jersey; high pressure steam, Minnesota and Wisconsin; high pressure water and vacuum trucks, New Mexico, Utah and Connecticut; and Jet Rodder trucks, South Carolina. New Mexico contracted some of their culvert cleaning operations. Georgia, Iowa and California use video equipment to supplement visual inspections of culverts. All other states performed inspections with the unaided eye of an inspector. Louisiana uses divers to inspect culverts which are underwater.

Drilled Shaft Inspection (and Measurement)

The major inspection technique was visual inspection. Inspections were performed from the top of the hole or by lowering a man into the hole (11 states) varying by state with some doing both. A significant number of states (twenty-two) did not perform drilled shaft inspections. Three states use pile construction and do not use drilled shafts--Maine, Vermont, and Idaho.

Florida and South Carolina use video equipment to examine the shaft. Arizona uses a gamma ray testing device and cross hole sonic logging. Washington has used sonic logging once.

Placement (and Retrieval) of Traffic Cones

Traffic cone placement is performed manually in all but 6 states which are using a semi-automated device. Ohio and Nevada have only one such device. Nevada is considering purchasing additional devices based on the device's performance in the Las Vegas area. Oklahoma, New York, Nebraska, and North Carolina have multiple devices. Virginia tested a device but did not like it and discontinued its use. Several states mentioned they did not use such devices, but some of the contractors working on state projects did.

Arizona and California have a modified truck which makes manual placement easier. North Carolina uses a truck with impact attenuators.

Non-Destructive Testing of Roadway Materials During Construction

The majority of states use nuclear density gauges for inspecting roadway density. Arkansas, Vermont, Indiana, Washington, New Hampshire and Massachusetts supplement nuclear density gauges with cores. Nebraska uses a falling weight deflectometer to supplement the nuclear testing. Rhode Island (except during construction) and Kentucky use only falling weight deflectometers. Georgia uses sonic testing. North Dakota uses cores only.

Underwater Structure Inspection for Scour and Corrosion

All underwater inspection is performed by state-employed divers, contracted out, or both. Rhode Island, North Carolina, California and Massachusetts use still photography to supplement the divers. Oregon, Michigan, Florida, North Carolina and Utah use video. Utah and California use a depth-finder from the surface to inspect the river bed. Iowa and Illinois use a sonar technique.

Pennsylvania currently contracts their underwater inspection but is pursuing research into sonic and seismic methods as well as ground penetrating radar.

Luminaire and Traffic Signal Bulb Replacement

All traffic signal and luminaire replacement was either manual, contracted, a combination of these, or not a state responsibility. Traffic signal bulb replacement was a city responsibility in several states. Luminaire bulb replacement was performed by the utility company in some locations.

LITERATURE REVIEW

To determine the present use of robotics or automation in each of the selected applications, database searches were carried out. Two databases were searched. The INSPEC database was searched after the "short list" of 17 was identified by the working group. Additional searches were performed in the TRIS database after the "working list" of seven tasks was selected by the advisory committee. Manufacturers who were found to have equipment applicable to the areas were contacted to request literature. Appendix H contains a list of the manufacturers contacted.

INSPEC Database Search

As stated above, an information search was carried out in the INSPEC database after the "short list" of 17 applications was selected by the working group. The search process consists of specifying a series of "key words" and a Boolean logic combination for those words. A list of titles of articles which contain the specified combination of words is then generated.

Titles selected had the following key words: at least one of (construction, industry, civil, engineering, transportation, building, bridge, road, or highway), and at least one of (robots, tactile, sensors, computer, vision, image, sensors, automatic, guide, vehicles, flaw, detection, ultrasonic testing, material testing, or non-destructive testing). The search was limited to the years 1990 through 1993 and produced a list of 855 article titles. These 855 titles were reviewed to determine which articles had a relationship with the 17 short list applications. A total of 148 articles were selected as potentially applicable.

A search through the Texas A & M library produced most of the abstracts of these 148 articles. The abstracts were reviewed and approximately 35 abstracts seemed to have bearing on one or more of the 17 short list applications.

TRIS Database Search

An information search was carried out in the TRIS database for six of the seven applications on the working list selected by the advisory committee. A search for articles relating to traffic signal and luminaire bulb replacement was not performed. Searching techniques for the TRIS database are similar to those for the INSPEC database.

The key words (flagging or flagger) produced 67 titles for the Flagging for Traffic Control application. After a review of these titles, 21 abstracts were acquired.

The key words (culvert, sewer, drain, or pipe) and (inspect, video, or camera) produced 368 article titles, and the key words (culvert) and (clean, debris, sediment, or clear) produced 71 article titles for the Culvert Clean-out and Inspection. After a review of these titles, 74 abstracts were acquired.

The key words (drill or shaft) produced 2 article titles for the Drilled Shaft Inspection application. Neither of these articles were applicable to this application.

The key words (traffic cone, lane cone, delineator, or marker) produced 76 article titles for the Placement or Traffic Cones application. After a review of these titles, 8 abstracts were acquired.

The key words (pavement, base, asphalt, highway, non-destructive or subbase), and limiting the search to the years 1980 through 1993 produced 249 article titles for the Non-Destructive Testing of Roads and Highways application. After a review of these titles, 85 abstracts were acquired.

The key words (underwater, under water, subaqueous) and (bridge) and (inspect) produced 46 abstracts for the Underwater Structure Inspection -- Scour and Corrosion application.

Flagging for Traffic Control

The primary function of traffic control procedures in work zones is to move traffic safely and expeditiously through or around these zones (1). These traffic control procedures are communicated to traffic via signs both active and passive and by work zone personnel. Work zone personnel are referred to as Flaggers.

Flaggers are used in many work zone traffic situations where dynamic communication is considered necessary. The flaggers main function is to communicate to the drivers what is expected of them. The three operations in which flaggers are most used are: the "stop traffic," "get attention," and "avoid obstacle" operations. Flaggers use STOP/SLOW paddles, red/orange flags, or lighted red wands to communicate with drivers (1).

In addition to using human flaggers for a "stop traffic" operation, (1) states that "Traffic control signals may be used for special (flagging) applications ..." and includes "... one-way traffic operations" as one of these special applications. For these temporary "stop traffic" flagging operations, European countries and Japan have been using electrical/mechanical signaling devices for many years. However, these electrical/mechanical devices generally have not been accepted by DOT management here in the US (2).

A two-signal, battery-powered, quartz-timed, wireless "stop traffic" system that is controlled by pre-set timing or traffic was tested by Texas A&M University (originally designed in West Germany). The system was found to work well (3). A Texas Transportation Institute (TTI) study (4) concluded that the use of portable traffic signals will save on flagging costs. However, the study also suggested, "...the potential for vehicle accidents within the work zone may be higher...because of occasional driver noncompliance with these signals."

Several studies of speed-reducing, "get-attention" flagging operations have indicated that humans have a slight edge over non-human devices in getting drivers to reduce their speed (5). Flagger training and appearance is also a factor in driver compliance (5,6). Several studies have concluded that the use of police officers in flagging operations has a significant positive impact on driver compliance (7).

In "stop traffic" flagging operations, the use of a timed-cycle portable traffic signal is an obvious choice, but the sensing and utilizing of real-time traffic flow information will decrease traffic wait time (5). During the last few years many sensors and computerized methods that can sense and utilize real-time traffic flow information have been developed.

For traffic sensing in dark conditions, Japan has installed an image-based traffic measuring system in twelve tunnels on the Hokuriku Expressway. The system uses ITV cameras to sense the head or tail lights on vehicles. This system is capable of acquiring real-time traffic flow rate, distance between cars, traffic volume, and traffic congestion (8).

Another video-based system for traffic monitoring can determine in real time the position, speed, and class of vehicles in a viewing range of 0 to 100 meters. This low-cost vision system uses a 386 PC (9).

Bristol University in the United Kingdom has developed a transputer-based image processing system (called TIPS) to monitor road traffic in real time. This system with its detection and tracking algorithms coded in Occam runs on a network of transputers (10).

Hitachi Ltd. of Japan has developed an image processing system using their HITACHI-IP/200 image processor that will measure traffic flow. The system uses real-time gray scale image processing and parallel image features extraction to track vehicles moving as fast as 150 km/hr (11).

Culvert Inspection and Cleaning

A culvert, being a small bridge, requires quality construction. During and immediately after construction, it is important to thoroughly inspect the culvert interior for cracks and open joints. From an inspection, as well as a cleaning point of view, culverts need to be divided into two groups.

One group, large culverts, are 4 feet (1.2 meters) or more high and can be comfortably entered by workers for inspection and cleaning. The other group, small culverts, are less than 4 feet high and are too small for workers to comfortably enter for inspection and cleaning. The inspector must have devices or methods to enter and view the interior of culvert.

PLS International company in Cleveland, Ohio makes a portable system which has been used for culvert inspection. Their "Pipe Crawling Robot" can transit pipes or culverts of 1000 linear feet (305 meters) in length with diameters as small as 6 inches. Also, DTS Inspection Services Company, Inc. in Houston, Texas and Intertest Company, Inc. in Flanders, New Jersey have both developed pipe crawling systems that several cities in the US are presently using to inspect sewer networks (12).

Generally culverts and sewers are straight but some do have bends. The PLS International's "Pipe Crawling Robot" can negotiate turns of 90 degrees in pipes or culverts as small as 12 inches (30 centimeters) in diameter. The tether operated robot can carry hydrostatically tested lights and a high resolution CCD color 360-degree rotating camera as well as several other types of sensors that can determine horizontal and vertical deflection, longitudinal distance, and depth penetration of specific anomalies such as wall coating erosion or corrosion (13,14).

The Sverdrup Corporation in St. Louis, along with the Metropolitan Sewer District of St. Louis, conducted research in the area of void detection around sewers. They tested three methods to detect voids. They used a falling weight deflectometer, ground penetrating radar, and infrared thermography. The infrared thermography used sophisticated infrared scanning equipment to detect subtle temperature differences in the pavement that might be caused by voids. The three methods were tested on a 500 foot (152 meters) section of roadway. Each detected some voids, but the infrared thermography gave the best results, 80 percent success rate, while the falling weight deflectometer gave the worst results (15).

The British Gas On-Line Inspection Centre developed a neutron-emitting pipeline pig that is capable of identifying the lack of seabed support under offshore pipelines. The system uses a neutron-interrogation method to quantify the extent of free-spanning pipeline where the seabed beneath the pipe is eroded. On one tested pipeline the free-spanning determination gave similar results to a previous remotely operated underwater vehicle inspection of the pipeline the year before (16).

Between 1978 and 1989 Iowa installed nearly 3000 miles (4827 kilometers) of 4-inch (10 millimeters) diameter longitudinal edge drains along their primary and interstate highways. To inspect these drains Iowa used fiberscopes and a video-image scope system that is only one half inch (10 millimeters) in diameter. In addition, they compiled a videotape to be used as an informative tool for personnel in the design, construction, and maintenance departments. These videos have influenced changes in maintenance, design and construction inspection for highway drainage systems in Iowa (17).

To assist in culvert inspection the U.S. Department of Transportation's stand alone "Culvert Inspection Manual" supplement to the "Bridge Inspector's Training Manual" provides procedures for conducting and documenting culvert inspections (18). In addition, Simmons-Boardman Publishing Corporation published a two-part culvert inspection manual for the railroad industry (19).

For small culvert cleaning, Hydro-Services of Missouri City, Texas has developed a high pressure, 12,000 pounds per square inch (843.6 kilograms force per square meter), water jet system they call the "Mole." This device, which has been extensively field tested, uses a unique method to advance and twist a high pressure hose into the culvert. The twisting hose and special end nozzle thrusts its way through any blockage, cleaning the culvert as it advances (20,21). One major advantage to this device is that the operator and the machine are located to the side of the culvert out of path of the water and debris that is exiting the culvert.

Researchers have noted that if one is to clap hands at one end of a culvert and listen you will hear a sharp echo of the hand clap followed immediately by a "whistler." The "whistler" sound starts at a very high pitch and then descends swiftly to a long lingering final note at a frequency that is dependent on the length and the diameter of the culvert (22). For example at the San Francisco Exploratorium there is a tube (culvert) that visitors can experience this "whistling." The length of the tube is 100 feet (30.48 feet) with a diameter of 18 inches (45.72 centimeters). The final note of the "whistle" has a frequency of 435 Hz and is audible for nearly one second. Further experiments into this "whistler" effect may show that it can be used to indicate debris or sediment in a culvert.

Drilled Shaft Inspection and Measurement

Drilled shaft inspection presents some of the same problems encountered in culvert inspection. However, regardless of the shaft diameter it is considered unsafe for a human inspector to descend into the shaft unless the shaft is cased. For quality inspections, therefore, a vision device is required to "see" the condition of the bottom and the side walls. For vision in air-filled drilled shafts, many video camera systems can be used.

The PLS International Pipe Crawling Robot has been used to record the conditions in large gas-filled bore holes (14). Also the Geophysical Applications section of the Southwest Research Institute's Electronic Systems Division developed a video inspection system for bore holes (23). This system uses a 45-degree mirror and camera arrangement to see down the bore hole and inspect the walls of the bore hole. The video information as well as depth and compass direction is recorded on tape.

The County Roads Board of Victoria in Melbourne, Australia developed a diving bell type system for very deep water-filled shafts. The diving bell houses a waterproofed video camera and can go to depths of 150 feet (45.72 meters). Once the bell is located at the shaft bottom, compressed air forces the water from the bell. This enables the camera to clearly view and record the material at the shaft base. The device has a water jet for cleaning the base and is also capable of taking soil samples from the shaft walls (24).

For actually "seeing" in water or slurry-filled shafts, sensors other than video are required. Japan has developed a robotic excavator for slurry-filled foundation excavations that uses ultrasonic sensors to determine the location of the walls and a computer to guide an excavator. The sensors are capable of "seeing" through the slurry to locate the walls of the excavation with precision (25).

Placement and Retrieval of Traffic Cones

In most states, the number of construction and maintenance work zone areas with traffic present is increasing. The number of traffic-related, work-zone accidents is also increasing (26). Next to the flagger, the cone-placing worker has the highest potential of being hit by traffic of any of the work zone workers.

Many work zones use cones to delineate the work zone area from a traffic area. The cones are placed or retrieved by work zone personnel, while many times the traffic is traveling at normal highway or road speeds immediately adjacent (1 to 5 feet, 0.3 to 1.5 meters) to the operation. The cones are placed and retrieved by the cone worker riding down close to the road assisted by another worker on a trailer or truck driven by a third worker. The direction the cone-placing operation is traveling usually positions the cone worker between the on-coming traffic and the cone trailer or truck.

The "Cone-Wheel," a cone placing and retrieving device developed by ADDCO Manufacturing Co. of Minnesota, has one major advantage over the manual method described above. The cone worker on this device is positioned up off the roadway inside the bed of the trailer or truck on a seat with a seat belt. The device has a large wheel (4+ feet, 1.2+ meters diameter) that pinches and grips the cones for placing and retrieving. It is designed to be easily removed from or mounted on either side of the trailer or truck usually on the traffic side. During the placing operation the cone worker places the cones in a upside-down position into the large pinch wheel. The cone worker may be assisted by another worker while a third worker drives the truck. Placing and retrieving can be accomplished at speeds up to 20 miles per hour (35 kilometers per hour)(27).

A fully automated cone placing and retrieving system has been developed in Japan. The automated truck device requires only one cone worker or operator. After setting the controls regarding the cone placement spacing, the operator just has to concentrate on driving the truck. The operator is located in the truck cab, which is positioned furthest from the on-coming traffic during placing and retrieving operations. The truck holds more than one hundred cones and can place and retrieve cones while traveling at up to 6 miles per hour (10 kilometers per hour). There is also a large lighted sign on the top of the truck to warn traffic of the cone placing operation(28).

Non-destructive Testing of Roadway Density During Construction

NDT of Concrete Pavements

Density. Designers have found that concrete density is in direct relationship to the durability of the concrete. Concrete slabs with higher density are more durable. When measuring the density of thin layers (1 to 4 inches, 2.5 to 10 centimeters) many gauges have difficulty ensuring that the underlying material does not influence the results. Troxler's model 4640-B thin layer density gauge will give accurate density readings of concrete overlays of 1 to 4 inches (2.5 to 10 centimeters)(29). Current research at Texas A&M University is investigating the use of ground penetrating radar to determine the density of concrete pavements. The results are reported to be very promising (30).

NDT of Asphalt

Density. The asphalt density of the compacted road is one very important indication of the quality of the road. In the past the only method to determine density was to drill a core sample of the road and have a laboratory test the density. However, in recent years the Troxler Electronic Laboratories has developed a very rugged continuous density gauge that can be mounted on the back of a roller (29).

This easy-to-use system indicates on an LCD display at the operator's console the direct density readings in either U.S. or S.I. units with an accuracy of 0.3%. In addition, the system has a 4-light indicator and an audible beeper that advises the operator how close the density is to the target density. For example, the green light on the console indicates when the density is within 1.5% of the target density and the red light indicates when the density is over 1.5% the target density.

When measuring the density of thin layers (1 to 4 inches, 2.5 to 10 centimeters) of asphalt, gauges have difficulty ensuring that the underlying material does not influence the results. Troxler's model 4640-B thin layer density gauge is not supposed to be influenced by underlying layers.

Current research at Texas A&M University uses ground penetrating radar to determine the density of asphalt roads. The results are reported to be very promising (30).

Operators that use equipment with a radioactive source are required to receive training and be licensed. The license is issued by the "Agreement State" or by the U.S. Nuclear Regulatory Commission (31). Troxler will for a small fee train and assist operators in obtaining this license.

Underwater Structure Inspection - Scour and Corrosion

Scour Inspection

Scour damage at bridge piers is caused by fast-flowing water. The pier causes turbulence in the water flow. This turbulence erodes the river bottom or bank in the area of the pier causing scour damage. Even normally slow-flowing rivers can have pier scour problems during fast-flowing flood times.

Scouring that happens during periods of fast flow flood may fill in with sediment of fines and other loose material as the flow slows. These filled in areas may appear to the eye as not having scour damage. This can make it difficult to discern that pier scour damage has occurred.

To determine scour damage during times of fast water flow, the personnel at TxDOT Division of Bridges and Structures have developed a very simple inexpensive depth-sounding system. They mounted a conventional depth gauge transducer to the bottom of a regular recreational water ski. The bridge hydraulics engineers hang the tethered ski over the bridge side. The ski rides on top of the water sending the depth signals up an electric cable to the depth indicator mounted on a hand truck on the bridge. The hand truck facilitates carrying and storage of the ski, the rope, cable and the 12-volt battery power supply. It is a simple matter to determine the water depth at different locations by moving the ski to those locations. However, because the ski is hung from the top of the bridge indicating only the depth directly below the ski, it is difficult to get depths at locations upstream.

Another sonar scour system was developed for fast flowing rivers (flows exceeding 20 feet per second, 6.1 meters per second) by the American Inland Divers company in Houston, Texas (32). Their device is tethered to a light crane that lowers it into the river. The winged device is designed to use the water velocity to glide under the surface with enough upstream force to maintain a steady under the crane boom.

A 675 kHz high-resolution sonar transducer that can rotate about two axes is mounted on the bottom of the device. The two-axis rotation permits the sonar to be aimed at any point from the water surface down to the bottom and 360 degrees around the vertical axis.

The system is capable of automatically recording river bottom profiles at 2 degree horizontal increments with an accuracy of +/- 6 inches (15.24 centimeters) at a range of 300 feet (91.44 meters). These profiles can be shown on a video screen and a printer individually or they can be combined to form a colored, 3-D view of the bottom surface (32).

GeoAcoustics Limited of Norfolk, England has developed a "Geopulse" high resolution sub-bottom profiler system specially assembled for the measurement of scour around bridge piers (33). Their narrow-beam, 14 kHz transducer has three times the acoustic energy of conventional systems. This frequency and power allow the system to penetrate sediment down to the bottom of scour holes while providing the required resolution. The transducer is mounted on a light-weight catamaran which is self-supporting in the water. The light-weight, easily-dissembled catamaran can be lifted by one person. The system produces three-dimensional, shaded, picture-like drawings of the bottom. Ground penetrating radar and color fathometers have also been developed and used to determine scour damage (34).

For scour detection, Simrad Mesotech has developed a multiple profile scan system that uses their 971 sonar system. The output from the sonar processor is recorded on a standard PC. Each completed profile identified with a horizontal azimuth and identification label. The transducer location is also calculated and stored. The program combines data and produces a three-dimensional graph of the area (35).

Structure inspection
In rivers and bays with water currents less than 2 or 3 miles per hour (3.2 or 4.8 kilometers per hour) and depths less than 100 feet (30 meters), human divers carry out the vast majority of the underwater bridge structure inspections. Several major problems, however, must be overcome.

Water Currents. One of the major problems that face divers in rivers and some bays is water currents. Diving in currents faster than 2 or 3 miles per hour (3.2 or 4.8 kilometers per hour) is considered impractical if not impossible. Even slow water currents force divers to expend a lot of energy. It can knock the face mask off, it can make it very difficult to carry bulky equipment, and it increases the possibility of injury.

Vision. Another major problem is vision in dirty water. Light does not penetrate more than about 2 feet (60 centimeters) in silty water. In order to see, divers must bring their own source of light. However, there are times when the water is so dirty that even this light will not penetrate enough to permit the divers to see. A clear-water box is one means divers use to see structures in dirty water. The portable box is made of a transparent material and is filled with clean water. This provides a clear view of structures adjacent to the box for visual inspection and photography.

Marine Growth. Marine growth covers the surfaces that the diver is to inspect. In fresh water, plant life covers surfaces. In salt or brackish waters, both plant and animal life cover surfaces.

Deep water. Depths of more than about 100 feet (30.48 meters) become a problem for divers. At those depths the time they can spend there without going through a long decompression period becomes very short. Also, the danger is much greater.

Communication and Data Recording. Another major problem is communicating or recording inspection data. Depths and locations are not readily apparent to divers. Writing under water is also difficult.

Industry has solved the problem of deep water and water with currents of 1.5 miles per hour (2.4 kilometers per second) or less. For example, Benthos, Inc. of North Falmouth, Massachusetts has developed several ROVs (Remotely Operated Vehicles) that are tethered and used by underwater inspection companies. These ROVs have thrusters that permits the operator, located at the surface, to completely guide them in this three-dimensional world to depths exceeding 1300 feet (400 meters). Both these devices can carry video cameras and articulated tools as well as many other types of sensors (36). Sea Hydro Products, Inc. has also developed a ROV that works similarly. No devices, however, were found that could be used in waters with currents faster than 1.5 miles per hour (2.4 kilometers per hour).

Corrosion is a major problem in steel structures. Baugh & Weeden of Hereford, England has developed an automatically-controlled system with a sonic probe that can be mounted on a ROV. This device is capable of determining the thickness of metal by taking two successive measurements of the member (37).

Luminaire and Traffic Signal Bulb Replacement

Data on robotic replacement of traffic signal bulbs was not found. The researchers, however, realize that the problem is not that the bulbs have to be changed. The problem is the location of the bulbs. Based on this realization, the suggestion of moving the light source to a more convenient location is forwarded. The light source can be located in the control box or on the side of the support pole and the light transported to the signal head with fiber optics.

Others

Concrete Pavements

Water/Cement Ratio. The ratio of the weight of the water to the weight of the cement is one of the most-important factors that determines the final compression strength of concrete. This water/cement (W/C) ratio has an inverse relationship with compression strength. In most designs, the designer specifies the minimum required concrete compression strength and a range for the water/cement ratio. The batch plant uses their approved concrete mix design for the concrete. To increase the workability of the concrete the operator is often requested to add additional water at the construction site.

Until recently, the inspector could only check the concrete's slump and make test cylinders or beams to verify the concrete meets specifications. The test cylinders or beams require at least seven days of curing before their strength can be determined, and the slump test does not provide any information regarding the strength or the water/cement ratio of that batch of concrete.

A device developed by Troxler Electronic Laboratories now allows an accurate measurement of the water/cement ratio of the fresh concrete within minutes (29). Their model 4430 water/cement gauge is easy to use. The tester places a sample of about four cubic feet (0.11 cubic meters) in a large bucket, inserts a radioactive source probe, then starts the test. Within one minute of starting the test, the gauge provides the W/C ratio with a precision of plus or minus 0.02 in a batch where the actual ratio is 0.55. This precision increases to plus or minus 0.01within four minutes .

Thickness of pavements is also important. The present method of thickness determination is to drill a core sample at about 1000 feet (305 meters) intervals. Falling weight deflectometer and ground penetrating radar systems are proving to be reliable, non-destructive methods of determining pavement thickness.

Asphalt Pavements

Asphalt Content. For asphalt content Troxler also makes two devices that will give quick and accurate test results that meets or exceed ASTM-D4125 requirements. With a range of 0 to 14% asphalt, these gauges give the asphalt content of a conventional sample to an accuracy of 0.084% within one minute, or an accuracy of 0.021% within 16 minutes (29).

Pothole Fixer. Research engineers at Northwestern University, Infrastructure Technology Institute are working on a prototype of an automated pothole repair vehicle. The vehicle employs some 70 controls and sensors and will be able to dig out and repair pot holes in seven minutes or less winter or summer. The vehicle first drills out the pothole cavity, vacuums out the cavity to remove all loose material, baths the cavity in hot air to 200 degrees Fahrenheit, and sprays the cavity with hot dry gravel and asphalt under pressure such that rolling is unnecessary(38).

Pavements General

Falling Weight Deflectometers have been used for several years. Foundation Mechanics, Inc. makes a system that has been used extensively (39). The Falling Weight Deflectometers (FWD) can determine pavement thickness and detect voids under the pavement in some cases. TxDOT owns and operates 12 of these devices that are trailer mounted. Spectral analysis of surface waves can be used to determine pavement surface thickness (40, 46).

In recent years several investigations were conducted using Ground Penetrating Radar (GPR). Some of these investigations were conducted at Texas A&M (41). These investigations have produced automated GPR procedures that can determine the pavement, base, and sub-base layer thickness, the layer's density, the layer's moisture content, the pavement asphalt binder content, and detect moisture-filled voids(30).

Bridge Cable Strands

A prototype Magnetic Perturbation Cable NDE system has been developed that can be used to inspect and monitor structural cable and strands of suspension bridges (42). The system was field tested on the Luling Bridge stay cables in 1988 (on Interstate 310 across the Mississippi river in Louisiana). This system now makes it possible to apply modern, quantitative, quality assurance strategies to suspension bridge cables.

SANDIA NATIONAL LABORATORIES ASSESSMENTS OF TASKS

As part of the investigation of tasks amenable to robotics, robotics experts at Sandia National Laboratories reviewed the tasks to suggest solutions. The reviews were conducted in a brainstorming fashion with a goal of providing many possible avenues for exploration. Some of the suggested methodologies are in preliminary stages of investigation. Most, however, have not been investigated at this time.

The Sandia researchers who reviewed the tasks include robotics experts and experts in non-destructive testing of structures. The robotics researchers have extensive experience with mobile robotics in unstructured environments including autonomous and tele-operated systems. The non-destructive testing experts have experience with structures ranging from aircraft to railroad bridges. Currently, they and Los Alamos National Laboratory researchers are completing non-destructive vibration tests of the old I-40 Rio Grande bridge prior to its disassembly. This is a rare opportunity to validate the non-destructive testing techniques.

Before discussing the suggestions of the Sandia researchers, it is important to discuss the Sandia approach to problem solving. In this context, the "Systems Approach" and "Evolution of Solutions" are relevant. The "Systems Approach" describes the importance of considering the system as a whole. This is important to identify the root cause of the problem and address it directly instead of correcting symptom after symptom. "Evolution of Solutions" highlights the fact that a good solution to a problem often involves many iterations. The first solution invariably, has misjudged the interaction with environment, resulting in operational problems. The problems, however, provide valuable insight and enable a next-generation solution to be superior to the previous iteration. Thus, a good solution is often the result of multiple solution iterations and testing. With this in mind, some of the suggested ideas are methods that restructure the environment to eliminate the problem, or the idea may be to evaluate and test existing equipment to improve the understanding of the problem.

This chapter describes the ideas suggested by researchers at Sandia National Laboratories. The highway construction and maintenance tasks discussed are culvert clean-out and inspection, drilled shaft inspection and measurement, underwater structure inspection for scour and corrosion, non-destructive testing of roadway during construction, traffic signal and highway illumination bulb replacement, flagging for traffic control in work zones, and placing and retrieving traffic cones in work zones.

Culvert Clean-Out and Inspection

The culvert clean-out was viewed as complementary to the inspection process, but different equipment would likely be required for each task. The main difficulty is that the clean-out equipment will probably need to be rugged, while the inspection task may require sensors that are not amenable to being ruggedized.

Both clean-out and inspection require a method for moving through the culvert. Suggested solutions fall into two basic categories—crawlers and snakes. Combinations of the two methods were also discussed. The crawlers are tracked or wheeled, mobile, autonomous or tele-operated robots to carry or drag equipment through the culvert. Snakes are cables that can either be pushed or pulled through the culvert. A cable might be initially pulled through the culvert by a crawler.

For the crawlers, two important needs were highlighted, sufficient traction and operator feedback. Large traction forces are needed because a crawler is likely to drag heavy supply hoses and cables, and the clean-out operation is likely to generate significant reactive forces. A heavy crawler is one solution, but deployment problems and a large size, limiting use in smaller culverts, were viewed as drawbacks. Suggestions to solve the problem included bulldozer-style tracks and wall-grabbing designs where the crawler pushes against the walls. Feedback to the operator was determined to be important because of the unstructured nature of the clean-out. Most of the material removed is likely to be dirt and small rocks, but large rocks, tires, and other unforeseen objects may require special action. The best way to handle the situation is to let the operator handle the problem. Therefore, the operator needs to be informed of the status of the cleaning. Force feedback and ruggedized video systems were suggested as methods of keeping the operator informed.

The main suggestions for the action end of the crawler were a scoop/shovel, water-jet, rotary pipe cleaner, and a saw to cut up tires, roots and other large objects. The scoop and the saw definitely require a movable arm to operate, but a water jet could also benefit from the positioning capabilities of an arm. The water jet was the most popular method to loosen the debris because it simplifies the removal of the material. The main suggestion for transporting the loosened material from the culvert is a vacuum system. The vacuum system also has the advantage of easy collection of the removed materials.

The snakes were not as popular as the crawlers because of the difficulty of dealing with bends in the culvert. There was, however, one interesting suggestion, a chain with one-way scoops. The idea is to oscillate a chain back and forth in the culvert. In one direction, scoops fold out from the chain and drag material. On the return stroke, the scoops fold flat against the chain, leaving the material behind. Thus, the back and forth motion of the chain ratchets the debris out of the culvert.

The inspection discussions focused on three technologies, optical, sound, and radar. The optical techniques included laser profiling scanners and video cameras. The laser profiling would yield a more quantitative result while the video systems offer a more user-friendly but more qualitative solution. The main disadvantage of all optical techniques is their inability to examine the soil conditions behind the culvert walls. The sound techniques considered were ultrasonics for interior wall inspection and wall tapping techniques for through-the-wall inspections. The wall tapping would search for voids behind the wall using the same technique that a carpenter uses to locate studs in wall. The ultrasonics may have application in locating voids, but the ground penetrating abilities of high frequency sound needs to be explored. Ground penetrating radar, however, was viewed as the first method to investigate, because ground penetrating radar systems are well developed and are commercially available.

Drilled Shaft Inspection and Measurement

The drilled shaft inspection task has many similarities to the culvert inspection. Thus, many of the same techniques suggested for culvert inspection are applicable.

For dry holes, a video camera could be used, but it has little advantage over the present light and mirror system. A camera system's main benefits would be an improved ability to inspect belled shafts and a video recorder could readily provide a record of the inspection. The main problem with both the camera and mirror system, however, is that the result is qualitative rather than quantitative. To address this issue, a scanning laser to profile the hole was suggested. Similarly, scanning ultrasonics could be used to map the shaft. Both methods would provide good quantitative records of the shaft profile.

For slurry-filled holes, sonar was suggested. An array of listening sensors with a single pinger could likely provide an accurate quantitative map of the shaft. Another possibility for the slurry filled holes is the ground penetrating radar.

For positioning the rebar in the shaft, electrical contact with ground was suggested. Electrostatic methods might be applicable for positioning rebar in slurry-filled holes.

Underwater Structure Inspection for Scour and Corrosion

The researchers' discussions on underwater structure inspection focused on two main issues, mobility and inspection techniques. The operational difficulties of working in water coupled with the desire to function during flooding and other rapid-water conditions highlighted the fact that moving about and holding position is a significant task.

Discussions always started with interest in using one of the many commercially available underwater inspection robots. Certainly, this option should be explored. Nevertheless, there were two areas of concern with present underwater robots—possible insufficient thrust and black/turbid water operation. Many of the systems are likely designed for ocean or lake operation where fast currents are not as common. Many roadway structures, however, cross rivers and other moving bodies of water. Therefore, a robot would require strong thrusters to operate in the fast-moving, often turbulent waters. Turbid water is a concern because most commercial systems use video cameras for local navigation and operation. Thus, turbid or black water would blind the systems.

To address mobility concerns, two ideas were suggested—anchors and structure grabbing. The initial anchor idea was to place an anchor upstream of the structure to hold the robot, then use thrusters for side to side operation. A second anchor proposal suggested two anchors, one on each bank of the stream. This arrangement provides positive control of both upstream/downstream and side-to-side motion. The structure-grabbing methods center around holding position by anchoring to the structure. Due to the large variations in structures, this was viewed as difficult but not impossible. For new construction, it was suggested that robot friendly anchor points could be integrated directly into the structure.

The inspection task suggestions were in two general categories—automation of existing procedures and non-destructive testing methods. The automation suggestions included robotic cleaning of underwater surfaces, acoustic surface imaging, and robotic test probe to check foundation soil conditions. The non-destructive test techniques can test structure as a whole or be applied to sections. Suggestions included ground penetrating radar, shaker excitation and monitoring, and acoustic response analysis. Currently, Sandia National Laboratories and Los Alamos National Laboratories are exploring several non-destructive techniques for assessing the health of structures. This work should certainly be reviewed for application.

Non-destructive Testing of Roadway During Construction

The two technologies suggested for non-destructive testing of the roadway are radar and magnetic equipment. The radar suggestion was ground penetrating radar integrated into a vehicle to provide a roadway profile while driving over the surface. The magnetic technology was to use a metal detector. Small metal disks could be randomly distributed before laying the pavement, then a detector could be used to measure the pavement thickness above each disk. Existing systems, using vibration or radiological emission, appear to be valid techniques and they should be evaluated.

Traffic Signal and Highway Illumination Bulb Replacement

The task of robotic replacement of bulbs for traffic lights and highway illumination systems was considered difficult due to the wide variations in equipment and installation. Nevertheless, several suggestions were suggested for future installations. The first suggestion was to modify the fixtures so that they are robot friendly. The changes would likely not increase the cost of the fixture, but, as old fixtures are replaced, a robot friendly infrastructure would develop. A main suggestion for a robot friendly modification is the use of a snap-in light assembly. A robotic arm with a suction cup could easily change this type of light. A second idea was to replace the traffic light bulb with an array of high intensity light emitting diodes (LED's). An LED has a 100,000 hour lifetime, thus used in a traffic light application it has a life of over 15 years. For highway illumination, the suggestion was to use light pipes or fiber optics to conduct the light from a base-mounted light source to the desired emission point. This technique would reduce the weight of the luminary and allow a lighter-weight lamp pole.

Flagging for Traffic Control in Work Zones

Although this is more of a human factors problem than a technological one, two interesting ideas were suggested—a railroad crossing arm and an autonomous/tele-operated follow me vehicle.

The railroad crossing arm could be used in a variety of ways. It could be operated manually or completely automatic. The simplest manual operation would be an arm at each end of the work zone with an operator for each arm stationed safely off the roadway. This would increase the personal safety of the flag person while maintaining their presence for human factors reasons. A second method would be to use a single operator, who travels back and forth in a vehicle. At each end, the operator opens the arm to let vehicles enter then closes the gate and follows the vehicles to the other side of the construction area. The flagger's personal safety is improved because he is in a vehicle. The requirement for a person to be present to ensure motorist attention is also met by the person controlling the arm at each end. If the arm can control traffic without a flagger present, then completely automatic operation is possible. A video vehicle recognition system could be quickly installed to sense vehicles and the arms could be controlled with a traffic light type controller. The same video and remotely-controlled arm equipment also could be used in a manual mode by a flagger who is tele-operating the equipment from a central location.

The other idea is to use autonomous "follow-me" vehicles to lead vehicles though the construction zone. Two or more computer-coordinated vehicles could follow a prescribed course through the work zone. Laser or microwave anti-collision systems could be used to prevent accidents with equipment or workers crossing the path. The vehicles could be fully autonomous, but for safety reasons tele-operated or supervised autonomous operation was suggested.

Placing and Retrieving Traffic Cones in Work Zones

The primary suggestion for placing and retrieving traffic cones is to evaluate current traffic cone machines. The availability of machines demonstrates that the task is certainly amenable to automation. The real question is: why does the available equipment not meet the users' needs? Therefore, a primary recommended task is to determine the reason for the lack of use and address it. Proposing new solutions may simply repeat the same problems.

Conclusion

Reviewing the discussions as whole, one central topic emerged. The question for inspection tasks is: what should be measured? Half of the topics involved inspection, and every inspection task began with a discussion of what type of emissions should be used to probe the environment. Five basic choices were discussed, atomic particles (neutrons), electromagnetic radiation (light, radar, x-rays), electric currents and fields, magnetics, and vibration/sound (shakers, sound, ultrasonics). The discussions covered topics like: which emission choice?, what frequency?, what type of emitter?, what sensors are available? This suggests that a subtask to the automation research should be the investigation of measurement techniques for highway environments. A prime starting point would be an assessment of ground penetrating radar.

Assuming the reviewed tasks are representative of the type and difficulty of tasks required to maintain and construct highways, advanced sensing and robotic technologies have great promise for advancing the maintenance and construction of highways. Central to proper application is proper identification of tasks, considering the technological, institutional, and physical constraints necessary for effective solutions.

CONCLUSIONS

Conclusions are presented in the context of Figure 1 which is a representation of Phase Two of the implementation process—Subjective Filters. The conclusions represent the researchers' determination of the preponderance of opinions obtained from engineering design and management personnel, field personnel and experts, and information gathered through literature reviews and robotics experts.

Flagging for Traffic Control

This appears to be a human behavioral problem of the motoring public and not a technology problem of automating existing methods. Portable traffic signals seem to work best. No system, however, is reported as fool-proof. While some advancements in improving existing methods can occur, new methods should be explored such as devices that alert drivers with alarms in their vehicles to supplement current methods. Systems such as this may prove more effective than simply automating certain aspects of existing methods.

Culvert Clean Out and Inspection

This appears to be a regional problem. It is a serious problem, however, in those regions most affected. Methods using high-pressure water and vacuum are in limited use. These methods are reported to be expensive. Additional research is needed to identify more economical and simple methods.

Drilled Shaft Inspection

Some field personnel feel that the existing visual methods are adequate. Some management and design personnel, however, are concerned that better inspection is needed, especially for slurry holes. Technology is available to dimensionally map drilled shafts and provide a permanent record of the dimensions. Work should proceed to develop economical and user-friendly inspection devices.

Placement and Retrieval of Traffic Cones

Automation of this activity seems economically feasible only in instances where it represents a major portion of the work day in high density traffic areas. Two existing machines were identified. One in Japan is fully automated while one in the United States requires two workers to handle the cones in addition to requiring a driver for the vehicle. Additional research is required to development conceptual designs and perform economic feasibility studies. The number of machines needed must be determined before adequate feasibility studies can be accomplished.

Non-Destructive Testing of Roadway Density During Construction

This problem evolved into two separate issues–density of sub-base and base material and thickness of concrete and asphalt pavements. Existing nuclear testing is considered adequate by most field personnel for measuring the density of base materials. Higher coverage (profile data information) and less time-consuming methods are desired. Ground penetrating radar technology can potentially be used to perform this testing. Additional research is required, however to verify the effectiveness of this technology.

The existing method of drilling cores in new concrete pavements to determine thickness is costly and time consuming. Less costly and higher coverage methods are needed. Research has been conducted to verify that gound penetrating radar will work for this application. Limitations include fresh concrete (less than approximately two months old) and pavements over about 10 to 12 inches (25.4 to 30.48 centimeters) thick. Different radar frequencies can potentially solve the depth problem. This technology is ready for implementation. An implementation study is needed.

Underwater Inspection for Scour and Corrosion

Some field personnel feel that current inspection methods using human divers are sufficient. Some engineering design and management personnel would like to have more detailed data. Technology is available to increase the fidelity and coverage of the inspections. Remote visual inspection can be performed using existing remotely controlled submersible vehicles except in high velocity water conditions. Other sensor modalities will likely provide more-detailed information, especially in low visibility situations. Further research is required to determine desired data measurements and methods of obtaining the data from appropriate sensor technologies. Additional research is also required to determine appropriate modifications to existing remotely controlled equipment for use in high velocity conditions.

Traffic Signal and Luminaire Replacement

The importance of this task varies with rural districts generally not interested since they have few bulbs to replace. It is a very important problem in urban districts. The magnitude of this problem may be much greater than evidenced in this study since much of this work is done by power companies and cities and is not the responsibility of the State. It is believed that automating this task is not economically feasible at this point in time. Moving the light source to a more convenient location and using optical fiber to transmit the light to the signal head is suggested for further research.

Other Conclusions

As part of this research a review of the articles published during the last 3 years in the proceedings of the International Symposium on Automation and Robotics in Construction, Vols. 8-10, (43,44,45) was conducted. The data, which is included in Appendix A, shows that past research in the United States has emphasized "paper studies" (examining the theoretical possibilities of automation) rather than hardware development and actual testing. This emphasis has resulted in very few robotic techniques being implemented.

This review also shows that the Japanese have emphasized hardware development. Figure 2 shows a comparison between the emphasis of the articles published by Japan and the U.S.A. Hardware development leads to prototypes which, when implemented, in many cases increased productivity and quality. The Japanese construction industry, with its less competitive structure combined with government tax incentives, allows companies to think long term and invest in hardware development paying less attention to today's bottom line.

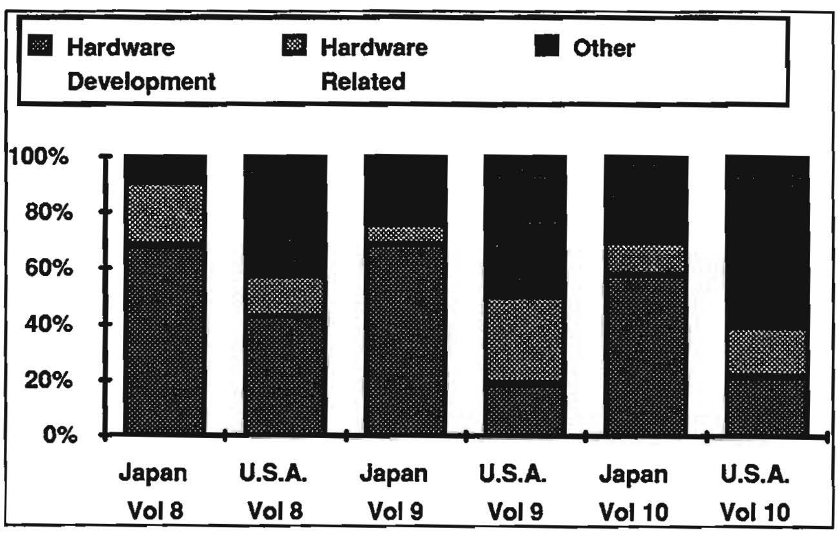

Figure 2 Hardware Development Japan Vs U.S.A

If robotic techniques are to be successfully implemented for the CMI of highways, then actual hardware must be built and tested under actual field conditions. A field level worker cannot improve job performance with a "paper study." Neither can the scientist conducting said "paper study" reach a valid conclusion that a piece of equipment will improve field performance, since he cannot know all the details of the tasks the field worker must perform and how the new equipment will interact with those tasks.

RECOMMENDATIONS

Flagging for Traffic Control
Drop from further consideration.

Culvert Clean-out and Inspection
Pursue phase three research--conceptual design and economic feasibility studies.

Drilled Shaft Inspection and Measurement
Pursue phase three research--conceptual design and economic feasibility studies.

Placement and Retrieval of Traffic Cones
Pursue phase three research--conceptual design and economic feasibility studies.

Non-destructive Testing of Roadway Density
Consider an implementation study of ground penetrating radar for pavement thickness. Additional research required to determine effectiveness in measuring density.

Underwater Structure Inspection
Pursue phase three research--conceptual design and economic feasibility studies.

Traffic Signal and Luminaire Replacement
Drop from the active list of applications due to complexity of the task.

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APPENDIX A

HARDWARE DEVELOPMENT COMPARISONS

Table A-1 The 8th International Symposium on Automation and Robotics in Construction, Paper Statistics (43)

Country	Hardware Development	Hardware Related	Others	Total
Australia	1	0	1	2
Belgium	0	0	1	1
Canada	0	0	1	1
China	1	0	0	1
Czechoslovakia	0	0	0	0
Denmark	0	1	0	1
Finland	3	0	0	3
France	0	3	1	4
Germany	17	7	8	32
Hungary	1	0	0	1
Israel	1	0	1	2
Italy	0	0	0	0
Japan	15	5	2	22
Poland	2	1	1	4
Russia	1	0	3	4
Saudi Arabia	0	0	0	0
Spain	0	0	0	0
Sweden	0	0	0	0
Switzerland	1	0	0	1
The Netherlands	0	0	1	1
United Kingdom	2	0	2	4
United States	3	1	3	7
Total	48	18	25	91

Table A-1 The 9th International Symposium on Automation and Robotics in Construction, Paper Statistics (44)

Country	Hardware Development	Hardware Related	Others	Total
Australia	1	0	0	1
Belgium	0	0	0	0
Canada	0	0	0	0
China	0	0	1	1
Czechoslovakia	1	0	0	1
Denmark	0	0	1	1
Finland	0	0	1	1
France	0	0	2	2
Germany	0	0	2	2
Hungary	1	0	0	1
Israel	0	1	0	1
Italy	0	0	1	1
Japan	39	4	14	57
Poland	0	0	0	0
Russia	0	1	1	2
Saudi Arabia	0	0	0	0
Spain	0	0	0	0
Sweden	0	1	0	1
Switzerland	0	0	0	0
The Netherlands	0	1	0	1
United Kingdom	4	0	5	9
United States	3	5	8	16
Total	49	13	36	98

Table A-1 The 10th International Symposium on Automation and Robotics in Construction, Paper Statistics (45)

Country	Hardware Development	Hardware Related	Others	Total
Australia	0	0	1	1
Belgium	0	0	0	0
Canada	0	0	0	0
China	0	0	0	0
Czechoslovakia	0	0	0	0
Denmark	0	0	0	0
Finland	0	1	1	2
France	0	0	0	0
Germany	0	1	1	2
Hungary	0	0	0	0
Israel	0	0	1	1
Italy	0	0	1	1
Japan	15	3	8	26
Poland	0	0	0	0
Russia	0	0	0	0
Saudi Arabia	0	1	0	1
Spain	1	0	0	1
Sweden	1	0	0	1
Switzerland	0	0	0	0
The Netherlands	3	0	0	3
United Kingdom	2	2	5	9
United States	5	4	14	23
Total	27	12	32	71

Table A-1 The 8th, 9th, and 10th International Symposium on Automation and Robotics in Construction, Paper Statistics Summary(43,44,45)

Country	Hardware Development	Hardware Related	Others	Total
Australia	2	0	2	4
Belgium	0	0	1	1
Canada	0	0	1	1
China	1	0	1	2
Czechoslovakia	1	0	0	1
Denmark	0	1	1	2
Finland	3	1	2	6
France	0	3	3	6
Germany	17	8	11	36
Hungary	2	0	0	2
Israel	1	1	2	4
Italy	0	0	2	2
Japan	69	12	24	105
Poland	2	1	1	4
Russia	1	1	4	6
Saudi Arabia	0	1	0	1
Spain	1	0	0	1
Sweden	1	1	0	2
Switzerland	1	0	0	1
The Netherlands	3	1	1	5
United Kingdom	8	2	12	22
United States	11	10	25	46
Total	124	43	93	260

APPENDIX B

WORKING GROUP MEETINGS

APPLICATIONS OF ROBOTICS AND OTHER AUTOMATED TECHNIQUES TO THE CONSTRUCTION, MAINTENANCE, AND INSPECTION OF HIGHWAY SYSTEMS

Initial Working Group Meeting Agenda
May 21, 1993

Introductions (10 minutes)

Department of Transportation (JU)
TAMU / TTI (WB)

Project and Meeting Objectives (20 minutes)

Project Objectives (JU)
Meeting Objectives (WB)

Brainstorm Applications (45 minutes)

Generate a "long list" of possible applications for which robotics may be applied to the Department's operations. (WB - facilitator, DM - timekeeper)

Select Applications (15 minutes)

Select a "short list" of approximately ten applications recommended for further investigation and provide rationale for selection. (JU - facilitator)

Action Items (30 minutes)

- Prepare report of meeting results and distribute to Working Group members. (DM)
- Present meeting results and recommendations to Advisory Committee for their review. (JU and WB)
- Establish lines of communication for Working Group. (JU and WB)

Background for This Meeting

BARRIERS TO IMPLEMENTATION

- **TECHNOLOGY DEVELOPERS**

1. Historically promise more than they can deliver
2. Have little knowledge of practical applications
3. Have potential solutions "looking for" applications

- **POTENTIAL END USERS**

1. Historically conservative and like to use proven techniques
2. Skeptical of new technology due to previous disappointments
3. Historically had little input into development
4. Suspicious of high development cost and utility of product

- **ACADEMICS**

1. Solutions sometimes more important than problems
2. Tend to be isolated from practical considerations
3. Tend to focus on theory rather than results

- **OVERCOMING BARRIERS**

1. Develop interested and enthusiastic team
2. Identify important applications without considerations of what is feasible
3. Search for suitable technologies
4. Develop relationship with technology providers
5. Do not allow technologist to over-promise
6. Select initial applications with high probability of success
7. Build "path finders" before prototypes

APPLICATIONS OF ROBOTICS AND OTHER AUTOMATED TECHNIQUES TO THE CONSTRUCTION, MAINTENANCE, AND INSPECTION OF HIGHWAY SYSTEMS

Initial Working Group Meeting Minutes
Austin, TX -- May 21, 1993

Introductions:

The meeting started at 10:00 a.m. Because more people attended than could comfortably fit in the conference room and owing to the good weather, the meeting was moved to the tables outside the cafeteria. (This contributed to a relaxed atmosphere and hence to a very productive brainstorming session.)

Mr. Underwood introduced the working group members from TxDOT and Dr. Boles introduced the members from Texas A&M and TTI. Present for the entire meeting were:

Jon Underwood	R&D Engineer	D-10R	512-465-7403
J. R. Stone	District Engineer	District 2	817-370-6511
J. L. Beaird	District Engineer	District 11	409-634-4221
Tom Newbern	Supervising Traffic Engineer	D 18TE	512-416-3124
Vernon C. Harris Jr.	Bridge Planning Engineer	D-5	512-416-2205
Bill Neeley	Materials & Tests Engineer	D-9	512-465-7615
Greg Malatek	Research Engineer	D-10R	512-465-7642
Kimberly Strange	Research Engineer	D-10R	512-465-7642
Tom Yarbrough	Research Engineer	D-10R	512-465-7685
Walter Boles	Assistant Professor	TAMU	409-845-2493
Don Maxwell	Professor	TAMU	409-845-8964
Robert Adams	Graduate Research Assistant	TAMU	409-847-9252
Connie Flickinger	Student Technician	TAMU	409-862-4177

PROJECT AND MEETING OBJECTIVES:

Jon Underwood opened the meeting by describing the thinking that preceded the meeting and laid out the objectives for the first part of the meeting; i.e., the brain storming session. A summary of his remarks follows:

With the growth of robotics technology in recent years TxDOT needs to begin looking at its operations to determine those areas in which robotics technologies can be utilized to increase safety and decrease costs. The purpose of this initial feasibility study is to first identify areas of high risk and high cost in our Maintenance, Construction, and Inspection operations.

Second, the study is to identify the available robotics technology and systems that can be used to accomplish these functions safer and at less cost. The successful completion of this feasibility study will more than likely instigate more detailed studies in those areas with the highest potential of increasing safety and decreasing cost.

Walter Boles then laid out the agenda for the brainstorming process as follows:

> It is important, in the areas of problem solution and determination, to first determine and completely understand the problem, then, and only then, determine the problem solution.
>
> Therefore, the remaining portion of this meeting should consist of a brainstorming session to identify the applications in your area that may in some way be made safer and more efficient with the implementation of robotic techniques.

The Department personnel, over the next ninety minutes, generated the following list of possible robotics (or automated) techniques. This list formed the basis for most of the later analysis.

Brainstorm "Long List" Of Applications:

Possible Application	Problem Addressed
Culvert inspection.	Safety and cost. Too small for humans to do.
Storm sewer inspection.	Safety and cost. Too small for humans to do.
Underwater structure inspection.	Safety and cost. Difficult environment for humans.
Surveying (in traffic).	Speed, cost, and accuracy. Surveying in traffic is dangerous.
Placement of raised pavement markers.	Time consuming and labor intensive. Safety and accuracy.
Paint striping and dotting for paint lines.	Accuracy and safety.
Placement and retrieval of traffic cones.	Time consuming and labor intensive. Dangerous job in heavy traffic.
Flagging for traffic control.	Safety of workers. Improved communication. Improved traffic control. Warning (out of control vehicles).
Graffiti removal (aesthetics) on structures.	Safety and cost. Labor intensive.
Mowing and weed-eating.	Cost and safety. Labor intensive.

Possible Application	Problem Addressed
De-icing of structures.	Safety and cost. Effectiveness. Better traffic control.
Automation of bridge icing signs.	Cost. Labor intensive.
Sign removal, repair, and installation.	Cost, speed, safety. Effectiveness.
Pavement crack sealing.	Dangerous job in any traffic. Efficiency and cost. Labor intensive.
Filling vehicle tank with natural gas.	Large volume control and dispersion. Speed and safety.
Ditch maintenance, road sectioning, and trenching.	Speed. Location of utility cables. Grade control.
Drill shaft inspection.	Safety. More testing and higher quality of inspection.
Equipment operation—compaction rollers.	Speed and better coverage. Labor intensive, lack of attention. Quality improvement.
Pavement evaluation—non-destructive testing.	Accuracy and increased coverage. Automated evaluation and uniformity. Speed and safety. Labor intensive.
Application of pavement marking tape.	High traffic situations are dangerous. Should be done quickly and accurately.
Illumination and traffic signal repair.	Time limit for safety reasons. Labor intensive. Cost.
Asphalt placement.	Accuracy of pay item. Speed and safety.

Possible Application	Problem Addressed
Herbicide placement.	Safety for workers. Accuracy of placement. Volume control.
Building maintenance, repair, and custodial.	Labor intensive and costly. Effectiveness.
Building security, indoor and outdoor.	Labor intensive with low productivity. Safety. Resource management problem.
Sandblasting and repainting of structures.	Labor intensive. Safety. Quality control. Environmental control.
Bridge inspection.	Safety to workers and public. Labor intensive with low productivity. More inspection and better uniformity. Quality is an issue.
Sandblasting and repairing of concrete median barriers and bridge rails.	Labor intensive with low productivity. Safety. Quality and environmental control.
Non-destructive testing of roadways: density measuring and continuous monitoring	Speed and efficiency. Labor intensive. Quality improvement.
"Road kill" removal.	Safety to workers. Labor intensive. Unpleasant with sanitation/health issues.
Weld and connection inspection (inside of steel boxes).	Size too small for humans. Accuracy and uniformity. Safety.
Pothole repair and patching.	Safety all around. Speed and efficiency. Uniformity and quality of results.
Hazardous material investigation. Spill investigation and cleanup.	Environmental problem where speed and safety are issues. On-site material evaluation.

• Possible Application	Problem Addressed
Cable stay inspection -- bridges.	Safety. Accuracy and uniformity of results.
Temporary sign installation and removal.	Safety to workers and public. Conformance to standards. Uniformity and speed of placement.
Shadow truck operation.	Safety for workers. Labor intensive and low productivity.
Street Sweepers.	Safety. Labor intensive.
Litter removal and sorting	Safety. Labor intensive. Unpleasant with sanitation/health issues.
Inventory evaluation of departmental appurtenances.	Speed. Uniformity and accuracy.
Project video taping—construction photography automation.	Uniformity, accuracy, and speed. Improved documentation.
Plant fabrication; non-destructive testing of beam construction.	Uniformity and quality issues. Continuous monitoring of mix and placement.
On-site weather monitoring.	Uniformity and speed. Documentation.
Hot mix plant stack sampling.	Safety and accuracy. Environmental issues.
Traffic counting device installation.	Safety and speed of installation are issues in heavy traffic. Labor intensive.
High load detection and warning.	Safety. Cost effectiveness.
Material Handling.	Labor intensive. Safety to workers. Strength required.

Select "Short List" of Applications:

Upon the completion of the "long list" the Working Group prioritized and grouped the items on the "long list" and placed them on a "short list" of seventeen items. The subjects on this "short list" were recommended for further investigation.

Flagging for Traffic Control
Underwater Structure Inspection
Culvert Inspection
Storm Sewer Inspection
Drill Shaft Inspection
Bridge Inspection
Sandblasting/Repairing Concrete Median Barriers
Bridge Cable Stay Inspection
Weld and Connection Inspection
Placement of Traffic Cones
"Road Kill" Removal
Non-Destructive Testing of Pavement
Non-Destructive Testing of Roadway density
Spill Material Evaluation -- Hazardous Material Investigation
Material Handling
Illumination and Traffic Light Replacement
Sandblasting/Repainting of Structures

Adjournment:

Jon Underwood noted that the study was to be completed by the end of August 1993, he recommended that communications between TAMU personnel and TxDOT personnel not go through the normal formal channels. The participants agreed to this logic. He also noted that the first meeting of the Advisory Committee would take about 2 to 3 weeks to arrange.

In closing Walter Boles and Jon Underwood thanked all the participants for their efforts and contributions.

Applications of Robotics and Other Automated Techniques to Construction, Maintenance, and Inspection of Highway Systems

Second Working Group Meeting

September 3, 1993

Introductions:

The meeting started at 10:00 a.m. at Camp Hubbard as scheduled. The following members of the Working Group attended. Mr. Underwood thanked every one for attending and for their support during the project.

Jon Underwood	R and D Engineer	D-10R	512-465-7403
Tom Yarbrough	Research Engineer	D-10R	512-465-7685
J. R. Stone	District Engineer	District 2	817-370-6511
J. L. Beaird	District Engineer	District 11	409-634-4221
Tom Newbern	Supervising Traffic Engineer	D-18TE	512-416-3124
Vernon C. Harris Jr.	Bridge Planning Engineer	D-5	512-416-2205
Walter Boles	Assistant Professor	TAMU	409-845-2493
Don Maxwell	Professor	TAMU	409-845-7923
Wesley Scott	Graduate Research Assistant	TAMU	512-862-4177
Robert W. Adams	Graduate Research Assistant	TAMU	512-847-9252

Discussion:

Mr. Underwood began the meeting by restating the objectives of the project and that the objective of this meeting was to review the preliminary results of the study. Walter Boles lead off the technical discussion with a thirty-minute slide presentation. This presentation outlined: the study approach, progress to date, and recommendations for future study.

After the presentation, members of the Group expressed general satisfaction with the results but wished to emphasize the following points:

- Depending upon their position within the Department and depending upon their personal experience, the field work force and the engineering staff will have differing opinions as to the priority of some safety measures, of some inspection techniques, and so forth. This will create differing views as to the "value added" of each individual robotic application. Value added should be the most important evaluation criteria.

- It was felt that engineering judgment, not operational expediency, should be the criteria for prioritizing proposed robotics applications. The opinion was expressed that the design staff assumed that proper inspection was being carried out and that long-term performance of constructed facilities required adequate inspection.

Therefore, if some inspection details could be accomplished best by robotic techniques, then robots were an important item.

- The opinion was also expressed that applications with state-wide importance should be given highest priority. This includes "anything involving traffic" such as slow moving work zones. This includes all sorts of maintenance operations. If field crews were reluctant to follow proper safety procedures, then this might be a priority area for robots.

- The strong opinion was expressed that any scour inspection technique that required the use of a "crane on a bridge" was not acceptable because the inspection process might create dynamic loads exceeding the design capacity -- not to mention the traffic hazards created. Additional investigation should address the differences in debris between west and east Texas. Underwater inspection was felt to be an important topic and several costs saving circumstances were discussed.

- Drilled shaft inspection is likely to increase in importance as retirements create gaps in inspection experience. All area offices have video cameras and personnel are familiar with their operation; so, lowering a camera into a finished hole should not be a problem.

- When developing a robotic application, it is important that the entire mission or work-task be considered. The successful completion of the entire process: arrival at the worksite, deployment of resources, the work itself, restoration of the site, and departure may be as important as the work itself.

- With respect to the bulb changing problem, it was mentioned that fiber optics were being used for signs along the Interstate Highway in Colorado. Therefore, the use of fiber optics in traffic signals may now be feasible.

- With respect to future studies, participants recommended that investigations be limited to three or four items instead of seven.

- Pathfinder development (the next step) requires the identification of a "champion" at the area or maintenance level to provide work-task detail and assist with equipment testing and debugging. The committee felt that this was an important issue.

Dr.'s Boles and Maxwell thanked the committee members for their candor and advice. The meeting adjourned at 11:30.

APPENDIX C

ADVISORY COMMITTEE MEETINGS

Applications of Robotics and Other Automated Techniques to Construction, Maintenance, and Inspection of Highway Systems

First Advisory Committee Meeting

June 18, 1993

Introductions (5 minutes):

Texas Department of Transportation
TAMU/TTI

Project and Meeting Objectives (10 minutes):

Project Objectives:

1. Approach from user needs as opposed to available technology.
2. Aim toward hardware development instead of "paper study."

Meeting Objectives:

1. Review progress to date (see handout).
2. Review and approve application short list (see handout).
3. Agree on meeting date in August to select application(s) for future development.

Review and Approve Application Short List (40 minutes):

This application short list evolved as a result of the working group meeting held on May 21, 1993. At that meeting, the Working Group initially identified 47 possible application areas. The Working Group then selected a short list of 17 priority areas from the initial list. The selection was based upon perceived, need not upon degree of technical complexity. The Project Staff grouped these 17 priority areas into three levels of perceived degree of technical complexity.

The purpose of this meeting is to obtain the Advisory Committee's direction on selecting a working list of robotic applications on which to proceed.

Action Items (5 minutes):

1. Schedule a second Advisory Committee meeting in late August.

2. Prepare report of meeting results and distribute to Advisory Committee and Working Group members.

3. Prepare operational and robotic assessments for the August meeting (along with other Advisory Committee requests).

Applications of Robotics and Other Automated Techniques to Construction, Maintenance, and Inspections of Highway Systems

Objectives and Work Plan

- Determine where robotics techniques can be applied to the Department's operations
- Develop specific recommendations for implementation of promising techniques
- Use the approach of problem identification and definition followed by the search for solutions—not the reverse order

The work plan consists of the following tasks:

Task 1:	Identify Preliminary List of Applications
Task 2:	Assemble Advisory Committee and Working Group
Task 3:	Convene Advisory Committee and Refine List
Task 4:	Assess Operational Issues for Selected Applications
Task 5:	Convene Advisory Committee and Review Assessments
Task 6:	Assess Robotics Issues for Selected Applications
Task 7:	Recommendations and Final Report

Progress to Date

Tasks 1 and 2 are complete. Task 3 is scheduled for completion on June 18, 1993. Literature reviews and current survey of all highway departments is underway.

Deliverables

Project Deliverables	Status and Target Dates
Preliminary list of applications	Complete
Prioritized list of applications	June 18, 1993
Operational assessment report	August 31, 1993
Robotics assessment report	August 31, 1993
Draft final report	September 30, 1993
Final report	October 15, 1993

Meetings

The first Working Group meeting was held on May 21, 1993. The first Advisory Group meeting will be held on June 18, 1993. Other meetings are not yet scheduled.

Miscellaneous

TTI has verbal confirmation that Sandia National Laboratories (SNL) will provide assistance with the robotics technology assessment portion of this project. We plan to leverage the Department's resources on future developments by arranging for matching efforts from Federal entities such as SNL.

Applications of Robotics and Other Automated Techniques to Construction, Maintenance, and Inspection of Highway Systems

Application Short List

The Project Staff has categorized the Working Group's short list of applications into three groups: robot friendly, less robot friendly, and least robot friendly.

It is probable that the Project Staff will be able to complete the assessments of those applications in the first group and achieve significant progress toward assessments of two applications in each of the remaining groups.

Robot Friendly Group

- Flagging for Traffic Control
- Culvert Inspection
- Storm Sewer Inspection
- Drilled Shaft Inspection

Less Robot Friendly Group

- Placement of Traffic Cones
- Sandblasting/Repairing Concrete Median Barriers
- Non-Destructive Testing of Pavement
- Non-Destructive Testing of Roadway Density
- "Road Kill" Removal
- Spill Material Evaluation -- Hazardous Material Investigation
- Underwater Structure Inspection -- Scour Inspection
- Bridge Cable Stay Inspection

Least Robot Friendly Group

- Bridge Inspection
- Sandblasting/Repainting of Structures
- Weld and Connection Inspection
- Material Handling
- Illumination and Traffic Light Replacement

Applications of Robotics and Other Automated Techniques to Construction, Maintenance, and Inspection of Highway Systems

First Advisory Committee Meeting

June 18, 1993

Introductions:

The meeting started at 10:00 a.m. as scheduled. The following members of the Advisory Committee and TAMUS Research Staff attended. The Advisory Committee Members introduced themselves; Walter Boles introduced the other members of the Project Staff.

Frank D. Holzmann	Assoc. Exec. Director. TxDOT	512-463-0281
Marcus L. Yancey	Assoc. Exec. Director. TxDOT	512-463-8627
Roger G. Welsch	Assoc. Exec. Director. TxDOT	512-463-8672
Alvin R. Luedecke	Director. Trans. Planning	512-465-7346
Tom Yarbrough	Research Engineer.	512-465-7685
Walter W. Boles	Asst. Professor	409-485-2493
Donald A. Maxwell	Professor	409-845-8964
Robert W. Adams	Grad. Research Assistant.	409-845-9252
Connie J. Flickinger	Student Technician	409-862-4177
Richard M. Gallegos	Student Technician	409-764-7996

Preliminary Discussion:

Mr. Luedecke and Dr. Walter Boles noted the project and meeting objectives and gave a brief review of progress to date. A short and general discussion of the issues followed this review.

- In the United States most of the robotics work in the areas of maintenance and construction consists mainly of paper studies. In Japan, hardware development receives much more attention.

- In the context of this study, "Robots" are defined as electromechanical devices that are designed to assist humans in performing their assigned tasks—as distinguished from "Robo Cop," replacing workers.

- The approach that seems to work best is to first determine the specific nature of the problem, then search for solutions to that problem. Applications that reduce hazards to the public and to the Department's employees and/or increase efficiency should be considered first.

- As with any study of this nature, a thorough review of existing efforts is required to keep from "reinventing the wheel" on any selected target application. If technology and/or equipment is already developed that satisfies some of the requirements, it should be investigated.

- Any robot should include certain "must have" features. This is best determined from the experience of field personnel—particularly those who are performing the task now.

- Any robotic device developed must not be too cumbersome to use in the field under normal operating conditions. Two unsuccessful examples were cited.

Application Short List Discussion:

At a previous meeting the Working Group "brain stormed" a list of 47 items that they felt merited further discussion. Subsequent discussion at that meeting resulted in a short list of 17 application areas felt to be particularly important. The Study Staff grouped these into three categories: robot friendly, less robot friendly, and least robot friendly.

The purpose of this meeting was to obtain the Advisory Committee's direction by selecting a working list from this list or other applications on which to proceed. A summary of the Advisory Group's suggestions follows:

Robot Friendly Group:

Flagging for Traffic Control: There has been a some work in this area. Is there anything that can be applied to the Department's situation? Check the "must have" features.

Culvert Inspection: Modified to *Culvert Clean Out and Inspection.* "Stopped up" culverts are the most important.

Storm Sewer Inspection: Others are working on this problem, not a high priority.

Drill Shaft Inspection: Inspection must include verification of critical dimensions as well as visual inspection.

Less Robot Friendly Group:

Placement of Traffic Cones: Look at the Japanese equipment and compare to "must have" features.

Sandblasting/Repairing Concrete Median Barriers: There was little discussion of this topic.

Non-Destructive Testing of Pavement: Other people are working on this problem.

Non-Destructive Testing of Roadway Density: "During Construction" was added. It was noted at this point that the list had an operational bias and that some later effort may be required to generate one with more construction-related topics.

"Road Kill" Removal: This is an important item, but ill defined and probably complex.

Spill Material Evaluation - Hazardous Material Investigation: California has taken the lead on this; let's wait for developments.

Underwater Structure Inspection: This includes scour inspection and corrosion detection: This is an important part of "bridge inspection" and would be a good place to start.

Bridge Cable Stay Inspection: This is not a problem now but it will be in the near future. This is another part of "bridge inspection."

Least Robot Friendly Group:

Bridge Inspection: There was little discussion except as noted above.

Sandblasting/Repainting of Structures: There was little discussion of this topic.

Weld and Connection Inspection: There was little discussion of this topic.

Material Handling: There was little discussion of this topic.

Illumination and Traffic Light Replacement: This is a difficult and ill defined problem of some urgency.

Other Topics Mentioned:

Crack Sealing: Some working prototypes have been developed but are too large and too slow moving for practical use in field service.

Pot Hole Patching: Some working prototypes have been developed.

Guard Rail Washer and Painter: A working prototype has been used by the Department in the past.

Furniture/Equipment Inventory: This is an on-going and difficult problem. (This could be combined with an interior security robot with bar-code technology.)

The SHRP reports were cited as a good source of ideas and documentation of work in progress.

Working List Selection and Discussion:

Consistent with the recognized time constraints and the discussion above, the following topics were selected by the Committee for further Research Staff investigation:

First Priority:

Flagging for Traffic Control
Culvert Clean-out and Inspection
Drill Shaft Inspection

Second Priority:

Placement of Traffic Cones
Non-Destructive Testing of Roadway Density During Construction
Underwater Structure Inspection -- Scour and Corrosion
Illumination and Traffic Light Replacement

Closing Comments:

The committee agreed the next Advisory Committee meeting will be held in late August 1993, and requested that Jon Underwood schedule the actual date, time, and place.

Dr.'s Boles and Maxwell thanked the committee members for their input and the selection of the working list on which to proceed.

The meeting adjourned at 11:00 a.m. as scheduled.

Applications of Robotics and Other Automated Techniques to Construction, Maintenance, and Inspection of Highway Systems

Second Advisory Committee Meeting

September 7, 1993

Introductions:

The meeting started at 10:00 a.m. at the Greer Building as scheduled. The following members of the Advisory Committee and TAMUS Research Staff attended. Mr. Underwood thanked everyone for attending and for their support throughout the project.

Jon Underwood	R and D Engineer	512-465-7403
Roger G. Welsch	Assoc. Executive Director	512-463-8672
Alvin R. Luedecke	Director Transportation Planning	512-465-7346
Tom Yarbrough	Research Engineer	512-465-7685
Walter W. Boles	Assistant Professor	409-485-2493
Donald A. Maxwell	Professor	409-845-7923
Wesley Scott	Graduate Research Assistant	409-845-9252

Discussion:

Mr. Underwood began the meeting by restating the objectives of the project and that the stated objective of this meeting was to review the preliminary results of the study. Walter Boles lead off the technical discussion with a thirty-minute slide presentation. This presentation outlined: the study approach, progress to date, and recommendations for future studies.

After the presentation, the members of the Advisory Committee generally agreed with the results but wished to make the following specific points:

- During the conduct of the research a recommendation developed for a different approach to solving the Traffic Light Bulb Replacement problem. The approach involves moving the source of light (i.e., the bulb) from the actual signal head to a location away from the traffic stream. The light would then travel to the signal head via fiber optics from a laser source located in the signal control cabinet.

- Concern was expressed about the economic feasibility of culvert inspection. It was generally felt that human inspection was cheaper. The economics of culvert clean out should be investigated.

- When considering the "traffic cone problem," replacing and restanding the cones is just as important as placing and retrieving them.

- Items should be prioritized with Drilled Shafts as the number one priority. The measurement (and inspection) of slurry shafts was viewed as very important. Measuring (and inspecting) bell footings was considered significant, since the ability to do so would enable greater usage.

Dr.'s Boles and Maxwell thanked the committee members for their input and support. The meeting adjourned at 11:30 a.m.

APPENDIX D

APPLICATION ASSESSMENTS

Placing and Retrieving Traffic Cones in Work Zones

Background:
In many maintenance operations one or more lanes of traffic must be closed to allow access by work crews and equipment. One method of diverting traffic from work lanes to adjacent lanes is by the use of traffic cones. These cones are usually placed and retrieved manually by crew members riding (and leaning over the side or rear of) vehicles. This is a hazardous activity due to the exposure to traffic and the straining position crew members must assume to accomplish the work.

Automation of this task appears to be feasible only where placement and retrieval of cones represent a substantial portion of a day's work or in high traffic locations. Equipment does exist to partially automate this task (Japan, US, France). It is apparently more economical to place and retrieve cones manually in the vast majority of cases. Few cone machines have been sold or are in use in this country.

There has been extensive research in the delineation of work zones and standard practice is well documented. Any robotic application must conform to that standard practice.

Purpose:
Determine what situations merit the use of an automated cone placement and retrieval system. Develop a system to place and retrieve traffic cones in those circumstances. This system may involve modification of an existing system to suit the practices of the Department.

Constraints/Scope:
Cones are used to delineate temporary work zones. These work zones may be static or slowly moving. Typical examples are lane striping or pot hole patching.

The suggested application is any situation that requires the rapid placement and retrieval of large numbers of cones over a considerable distance; for example, a striping operation.

Cones may be placed according to standard specifications or according to specific situations; that is, spacing must be controllable.

Upon retrieval, cones may, or may not, be in their original position. They could be upright and out of position, they may be in position but laying down. Or they may be damaged.

System should be capable of operating at speeds faster than current manual operations.

Coning operations are related to the work being accomplished; that is, the actual placement of the cones is dictated by the location and nature of the work. The actual placement of the cones may be done by a regular member of the work crew and not by specially trained personnel.

Task Break Down Structure: Equipment Issues:

Arrive at Site:

Crew and equipment arrive at site in appropriate vehicle.		Should the work related arrival vehicle and the cone vehicle operate as a single unit or separately? How would this affect crew operations?
Activate vehicle safety system.		

Deploy Work Vehicles

Deploy additional safety system for situation at hand—signs and arrow boards.		Should signs and cones be combined on the same vehicle?
Position work vehicle at the up-stream end of work zone.		

Work—Put Out or Retrieve Cones:

Put out cones by driving forward and dispensing cones as you go.		Refillable magazine versus all cones in large magazines?
Take up cones by driving along the line of cones, taking up cones as you go. Note: some cones may have to be retrieved by hand.		Random toss into truck requiring stacking (by hand?) later; or, automatic stacking and loading of magazine later; or, reloading of magazine as you take up cones.

Recover Equipment and Restore Site.

Pull vehicle off of roadway when work is complete.		
Retrieve safety signs if appropriate.		

Depart from Site:

Retrieve any other safety equipment.		
Crew and equipment leave in arrival vehicle.		

Culvert Clean Out and Inspection

Background:
There are areas within Texas where culverts silt shut on a regular basis. These areas are characterized by generally sandy or sandy loam soil with flat terrain around the culvert. Rapidly running water picks up the silt elsewhere and carries it to the culvert location. The water slows down when it reaches the culvert location and the silt settles out around the culvert ends or within the culvert itself. Once the wet silt dries within the culvert, it hardens and becomes difficult to remove. While this is mainly a maintenance problem, it often occurs during construction. Silt must be at least partially removed during culvert extension.

It is difficult to completely clear silt from a completely stopped up culvert. Large box culverts can be cleared with a "Bob Cat" or a "Fresno." Culvert end areas and ditches can be cleaned with existing maintenance equipment. Small culverts present a particularly difficult problem because normal ditch maintenance equipment is too large to be of much use.

Department maintenance crews have used several approaches to tackle this problem. High pressure water hoses have been used with some success. Other solutions have employed the use of rods to punch through a pilot hole then a Fresno pulled back and forth until the silt is partially removed. A round Fresno made from disk-harrows has be used with some success on round culverts.

Several off-the-shelf systems have been used by contractor personnel to clean culverts. This usually involves the use of high-pressure water hoses with vacuum pick-up of waste water and silt. The hoses are either manually operated or machine operated.

A related, but more difficult, problem is the clean-out of storm sewers. Storm sewers have bends and drop inlets and tend to be smaller in size. Storm sewers stop up with trash, and invasive roots with silt deposits adding to the problem. This problem may not be as wide spread but is more serious when it does occur. Since the Department has a number of storm sewers within the scope of its responsibility, this should be considered as well.

Another related problem is the inspection of existing and new culverts. Culverts that have been cleaned should be inspected for structural integrity and general condition. In the case of new culverts, proper compaction of back fill material and washouts due to slipped joints and other construction-related questions are the issue.

Purpose:
Develop a machine that can be used by the Department's maintenance personnel: to clean silt from within silted up culverts and dispose of removed material in a satisfactory manner. If the silt is not contaminated, it can be simply moved to another appropriate site.

Inspection includes determination of effective cross-section, roof collapse, joint shifting, corrosion, back fill soil transport. Inspection of new culverts includes determination of proper back fill compaction and gradation. Inspection will require a second piece of equipment.

Constraints/Scope:
The arrival vehicle must be able to get close enough to support clean-out and inspection vehicles; or else, other supporting vehicles must be considered.

The arrival vehicle will be parked off-road but within the right-of-way. Traffic safety is not a big issue.

The clean-out vehicle and the inspection vehicle must be capable of moving to the culvert end under their own power or placed in position by the arrival vehicle. Otherwise they must be light enough to carry.

Culverts may be partially filled with water or completely dry.

Culverts of concern will be between 18-inches and 48 inches in diameter or maximum cross section. The smaller sized culverts should be considered most important. Culverts may be round, oval, or box in shape.

Culverts may be made of corrugated metal pipe, round concrete pipe, or square concrete pipe, or cast in place.

Development of equipment for the larger box culverts would the easiest; however, the smaller, round or oval culverts are the real issue.

Task Break Down Structure: Equipment Issues:

Arrive at Site:

Crew and equipment arrive at site in appropriate vehicle.		Assume Dump Truck with Trailer.
Crew deploys any required safety systems.		Road Work Ahead Signs, etc.

Deploy Work Vehicles -- may include multiple vehicles:

Move clean-out vehicle to culvert end.		Local power source will be required: electric generator most likely. LNG is a possible fuel source for generation.
Move inspection vehicle to culvert end.		May be by hand or teleoperation.
Set-up any required support systems.		Spare tools and expendable items must be available.

Work -- Clean out And Inspect Culvert:

Clean-out means that debris or compacted silt within the culvert must be pulverized or fragmented and removed. It may be wet or dry.		This may require two machines. Operator must be able to monitor equipment visually.
Inspect cleaned-out culvert means: determine effective cross section; detect collapsed roofs; detect corrosion; detect joint shifting and voids behind culvert walls while moving through culvert.		Ground penetrating radar? Odometry? Visual inspection by television?
Inspect new culvert means determining the density and gradation of culvert back fill material.		Ground penetrating radar? Visual by television?

Task Break Down Structure: Equipment Issues:

Recover Equipment and Restore Site.

Remove any trash and debris from site. Proposed test site has no environmental problems with heavy metal.		Assume that silt and any trash will be placed in supporting dump truck. Other transport means: conveyer? Vacuum hose?
Move any work vehicles from culvert back to arrival vehicle. This includes generators, pumps, etc.		Ditch maintenance equipment may be involved before and after clean out operations.

Depart from Site:

Retrieve any safety equipment .		
Crew and equipment leave in arrival vehicle.		

Drill Shaft Inspection and Measurement

Background:

The inspection of foundation drilled shafts during construction is a common occurrence within the Department's construction program. Typically, these shafts are drilled with a rotary auger; a reinforcing bar cage is lowered into the shaft, and then the shaft is filled with concrete. This type of foundation is used to support bridge abutments, bridge piles and piers, and other structural foundations. Current practice calls for shafts without a bell at the bottom. It is uncommon for shafts to be anything but vertical but inclined shafts do exist where required by the design.

Where the site is dry, the soil is firm, and other conditions are ideal, inspection is straight forward. Sun-light and a mirror are used to visually determine whether the bottom of the hole is free from debris. The shaft is assumed to be vertical; or degree of plumb is determined with a plumb bob. The diameter of the hole is measured at the top and assumed to be consistent over the entire length of the shaft. Bricks are tied to the outside of the reinforcing cage to ensure proper side spacing within the hole. A tremie is used to place the concrete from the bottom (of the shaft) up.

Where the sides of the shaft require support, the hole may be cased or filled with a drilling slurry, or both. This may occur where the site is wet or the soil is unstable for one reason or another. If a casing is used without a slurry, visual inspections and measurements are not a problem—unless the hole is filled with water. In this case bottom debris removal and inspection is a problem. If a slurry is used with a casing, visual inspection is impossible and down-hole measurements are difficult to obtain. The placement of concrete within the slurry to prevent voids is also a problem.

Purpose:

Develop (or recommend) a pathfinder that can be used to inspect for excessive debris at bottom of drilled shafts, and the condition of the side walls.

Constraints/Scope:

Drilled shafts are normally 24 to 48 inches (61 to 122 centimeters) in diameter and between 10 to 80 feet (3 to 24 meters) deep. Sloping shafts are rare (less than 2%) and should be ignored for this effort.

Belled bottoms are not common but should be taken into account. Since this type of shaft is near to impossible to inspect under current safety regulations, a reliable technique may increase their use.

The shaft may be filled with water or drilling mud slurry may be used to prevent side wall slump or collapse in wet or sandy soil. Equipment should be able to "see through" the slurry or through water.

Task Break Down Structure: Equipment Issues:

Arrive at Site:

Crew and equipment arrive at site in appropriate vehicle.		Four by four pickup with A-frame.
Crew deploys any required safety systems.		This is a construction work zone and safety rails, etc. should have been erected.

Deploy Work Vehicle:

Move arrival vehicle to shaft opening (each in turn).		
Position inspection sensor array over shaft opening.		
Turn-on equipment and check-out.		
Perform any calibration tests.		

Work -- Visually Inspect and Measure Drilled Shaft:

Lower array into shaft opening. This may occur before steel is lowered into the shaft.		This may involve a truck-mounted hoist/winch to raise and lower the sensor array.
Collect profile of side wall.		Visually inspect. Ground penetrating radar?
Collect cross-section data.		
Determine density of side wall material.		
Measure shape of bell, if any.		
Determine condition of shaft bottom and amount of debris.		
Determine position of rebar with respect to the shaft itself.		
Display data for operator's benefit and for documentation.		

Task Break Down Structure: Equipment Issues:

Recover Equipment and Restore Site.

Pull sensor array out of hole.		
Clean sensor array.		
Perform any calibration and shut down operations.		
Stow equipment for movement to another site.		

Depart from Site:

Retrieve any safety equipment .		
Crew and equipment leave in arrival vehicle.		

Flagging for Traffic Control in Work Zones

Background:

Flagging for traffic control and safety is required in many highway maintenance operations. Flagging is required for situations such as temporary one way traffic, construction equipment road crossings, temporary lane blockages, and to alert the motoring public to potential hazardous or small clearance work zones.

Flagging is usually accomplished manually by crew members. Many semiautomatic schemes have been tried such as the use of mannequins and portable traffic lights. For short term projects, none of the automated methods seem to work as well as manual flagging. The problem seems to be one of human behavior. Motorists appear to respect a human flagger more than an automated one. Even though technology is available to accomplish most any desired level of traffic control, removal of crew members from the hazardous flagging situation may not be feasible without substantial studies into human behavioral aspects and the effects of any automated system upon such behavior.

There has been extensive research in the delineation of work zones and standard practice is well documented. Any robotic application must conform to that standard practice.

Purpose:

Develop (or modify existing) mobile temporary traffic control system with substantial involvement of human behavior specialists.

Constraints/Scope:

This is a human factors problem—not a technology problem as such. There is considerable off-the-shelf technology available for immediate use. The difficulty has been in integrating the equipment into the required standard operation.

One of the key issues is the removal of the flag person from a hazardous position in or very near the traffic stream. Remote operation is a possible solution in some cases.

Another key issue is whether (or not) the new equipment will maintain or increase the effectiveness of the traffic control operation. In other words, increase the level of public safety.

If the flagging operation is associated with a mobile work zone, then it must also be mobile with short set-up and take-down times.

Extensive field testing will be required for validation.

Task Break Down Structure: Equipment Issues:

Arrive at Site:

Crew and equipment arrive at site in appropriate vehicle.		Work truck(s) with "safety trailer" containing equipment and signs, etc.
Crew deploys appropriate signs for the job.		

Deploy Work Vehicles:

Position crew and equipment at both ends of roadway to be controlled.		
Power-up and check-out equipment. Gather any site specific data required for operation.		
Gather any data and calibrate equipment.		

Work—Establish and Maintain Traffic Control:

Stop all traffic.		
Deploy any lane-marking equipment, e.g., cones and "flagging" equipment.		
Begin "flagged" operation. Maintain control over vehicle queues and be able to adjust for abnormal conditions.		
Keep drivers aware of current operational status at all times.		
Stop all traffic.		
Retrieve any lane marking equipment, e.g., cones, and remove "flagging" equipment.		
Resume normal operation.		

Task Break Down Structure: Equipment Issues:

Recover Equipment and Restore Site.

Turn-off equipment and stow in travel vehicle.		

Depart from Site:

Crew and Equipment leave the site in the Arrival Vehicle		

Traffic Signal and Highway Illumination Bulb Replacement

Background:
Replacement of bulbs for traffic signal and other highway illumination systems is time consuming, hazardous, and requires heavy equipment. Bulbs require replacement either because of failure or scheduled replacement. In some districts, for example, traffic signal bulbs are routinely replaced at predetermined intervals such as every two years. In some rural districts, bulbs are replaced by the local maintenance crews on an as needed basis.

The primary problem with these illumination systems is that the bulbs are located in elevated positions over active lanes of traffic. In order to change the bulbs, a truck with a lift system (bucket truck) is generally parked in an active lane of traffic while a crew member is elevated in the lift basket into a position from which bulb replacement can be accomplished. This causes interference with traffic and exposes crew members to hazardous positions.

Purpose:
Develop robotic techniques to replace traffic signal and highway illumination bulbs with supervisory or teleoperated control.

Constraints/Scope:
The task also includes cleaning reflectors and lenses and blowing out weep holes as well as the actual bulb changing operation.

While traffic signals tend to look the same, in fact wide variations in construction and rigging do occur. Those differences and some of the design details themselves, make this application difficult to automate. If a "robot friendly" design could be developed and if it were to find wide-spread use, this task might become feasible.

Weather conditions may prohibit work from taking place. Wind and vibration is a factor. Rain and snow are also factors.

Time is also a factor. If the work can be accomplished in 20 minutes or less, than elaborate lane-blocking procedures are not required.

Obviously traffic density is a factor. The heavier the traffic the more danger to the Department's work crew and the public.

It requires a great deal of manual dexterity to "handle" a luminaire; less so, for a signal light. In any event, touch and feel capability are required.

Device should be self contained in one unit like a truck. System should allow operator to stay in vehicle at all times.

Equipment should allow for manual replacement as a fail-safe measure.

The operation should include determination of damage to the signal head. Since actual repair of the signal head is not a part of this analysis, counter measures should be designed into the operation.

Task Break Down Structure: | Equipment Issues:

Arrive at Site:

Crew and equipment arrive at site in appropriate vehicle. Assume a one-person crew.		
Activate the vehicle's on-board safety system.		Integrated safety system is assumed.

Deploy Work Vehicles:

Move arrival vehicle under the signal light or luminaire to be fixed. This will depend upon the design of the vehicle.		
Driver moves to operator position.		
Power on and check out equipment.		
Raise the end effector / sensor array into position.		
Establish common frame of reference by clamping onto the signal head frame.		

Work Sequence:

Open Signal Head: Loosen cover clasp. Lower head cover.		
Change bulb: Remove old bulb. Dispose of old bulb. Select new bulb. Insert new bulb. Test new bulb.		
Clean interior of head: Wipe lens. Wipe reflector. Blow through weep hole.		
Close Signal Head: Raise cover into position. Tighten clasp.		

Task Break Down Structure: Equipment Issues:

Recover Equipment and Restore Site.

Deactivate safety system.		
Document successful (or failed) bulb change.		
Lower End Effector / Sensor Array to traveling position. Operator returns to driver position.		
Power off EE/SA.		

Depart from Site:

Crew and equipment leave in arrival vehicle.		

Non Destructive Testing of Roadway Materials During Construction

Background:
Inspection of roadway materials, by anything other than traditional means, during construction raises a number of technical and procedural issues. First, payment quantities are determined from in place measurements and not design quantities. Therefore, both the contractor and the Department must have confidence in the final result. Second, the quality of the final result rests with the quality of the inspection. Therefore, the inspection process must deliver consistent and accurate results. The real question to be answered is: can automated testing duplicate the precision of the traditional spot-tests and deliver an increase in accuracy resulting from broader coverage that will result in superior operational performance?

Pavement thickness is determined by drilling a hole through the pavement with a core drill. Once the pavement is cored, the core length is measured. A spacing of approximately 1,000 feet (305 meters) per drill hole results in widely-spaced precise readings. It has been suggested that a measured profile of thicknesses would yield superior results—even if individual measurements were not as precise as before.

The density of roadway material is measured by inserting a probe into the material. If the material is loose, this is not a problem. If the roadway material is compacted base, then a hole must be drilled for insertion of the probe. Some nuclear density gauges do not require holes, but applications are limited. Again, it has been suggested that a profile of measurements would yield superior performance results.

There are sensors available that will deliver the required profile results. The question is: will these sensors deliver the desired results under operational conditions in the field?

Purpose:
Develop (or redesign) automated techniques for measurement of concrete pavement thickness, the density of compacted subgrade, etc. during construction and during the assessment of maintenance requirements.

Constraints/Scope:
Results must reflect the same degree of precision as previous tests.

Coverage must be much greater than previous tests.

Tests must be run in parallel with previous methods until acceptance is assured.

The cost of operating two $75,000 drilling rigs could be used as a cost bench mark.

The elimination of nuclear density gauges would eliminate the Nuclear Regulatory Commission paperwork.

Task Break Down Structure: Equipment Concepts:

Arrive at Site:

Crew and equipment arrive at site in appropriate vehicle.		
Activate appropriate safety procedures.		

Deploy Work Vehicles:

Unload sensor array vehicle at the start of the test path.		
Power-up and calibrate equipment.		

Work—Measure Test Profile Data:

Move along designated path within work site and take a "profile" of readings.		
Communicate readings to support vehicle for rapid reduction of results.		
Displays should indicate problem areas for additional coverage.		

Recover Equipment and Restore Site.

Stow sensor array vehicle in arrival vehicle.		
Perform any required documentation task.		

Depart from Site:

Deactivate any safety equipment.		
Crew and equipment leave in arrival vehicle.		

Underwater Structure Inspection for Scour and Corrosion

Background:
There are a number of widely diverse circumstances where underwater inspection for scour and corrosion is an important issue. First, it is a part of a larger, mandatory bridge inspection program. Second, on-site conditions vary widely—structures along the coastal shore line subject to tidal erosion and salt-water corrosion to structures in the western desert subject to flash flood erosion. Some structures support roadways with heavy traffic that presents operating hazards. Other structures are in remote areas where access to the structure itself is a problem. Finally, since most of the actual inspections are accomplished by crews dispatched from Austin, the district personnel may not be aware of the operational problems associated with the inspection itself.

The scour inspection issues are related to the movement of water in and around the supporting piles and footings. Rapidly moving water (flash floods and tidal currents) may erode enough supporting soil to undermine the structure. This foundation soil may be replaced with silt after the erosion period making visual detection difficult. Turbid conditions may make visual inspection impossible in any event.

Corrosion inspection issues are related to the deterioration of the structure due to chemical action (e.g., rust) and/or fatigue.

Purpose:
Determine the physical condition and structural integrity of underwater structural supports.

Determine the evidence of possible scour that may endanger the structure by undermining the structural supports.

Determine stream flow during floods and other conditions when human inspection is hazardous.

Constraints/Scope:
Getting crew and equipment to and from the inspection site and the roadway is a considerable problem in many cases. This may be due to a combination of: distance to the accessible roadway, brush and rip-rap along the embankments.

Water may be "black" making visual inspection impossible. Fast-moving water may make access impossible. Detailed contour maps from sonar may not be cost effective.

Structural plans may not exist for bridges brought into the Department's area of responsibility after they were built.

Use of the roadway for long periods of time may not be possible; so, shortening the actual inspection time is important.

Task Break Down Structure: Equipment Issues:

Arrive at Site:

Crew and equipment arrive at site in appropriate vehicle(s).		
Get into position to deploy.		
If deployment site is located on the pavement, then take extensive safety measures. If not, take appropriate measures.		

Deploy Work Vehicles -- may include multiple vehicles:

Move sensor array vehicle to appropriate location. Power-up and test equipment.		
Calibrate equipment.		
Put equipment in the water.		

Work -- Bridge Inspection:

Move sensors to each of the collection points.		Surface area must be cleaned before it is inspected visually.
Collect and record data.		
Communicate data to support vehicle.		Wireless communication?
Reduce data and display for remote supervisor.		
Move about on direction from supervisor.		

Task Break Down Structure: Equipment Issues:

Recover Equipment and Restore Site.

Pull equipment from water.		
Shut down procedure.		
Power off.		
Move equipment back to loading position.		

Depart from Site:

Retrieve any safety equipment .		
Crew and equipment leave in arrival vehicle.		

APPENDIX E

INTERVIEWS WITH FIELD PERSONNEL

Date: August 16, 1993
Name: William R. (Randy) Cox
Title: Head of Underwater Inspection
Location: TxDOT, Riverside Drive, Bldg 150, Austin
Interviewers: Wesley Scott, Robert Adams

Underwater Inspection:

Discussion:

Above ground inspection of bridges is frequently done by contract. Bridge inspection is the responsibility of the District Engineer. All underwater inspection is performed by Randy Cox's team (District Engineers expect his office to do the inspections).

Underwater inspections are done using scuba equipment. Water must be flowing at less than 2 knots (3.704 kilometers per hour) preferably less than 1 knot (1.852 kilometers per hour) for divers to be able to work. Very often bridge structures must be cleaned before inspection. Hand scrapers are the most common means of cleaning, wire brushes have been used (will not work for barnacles on salt water structures) and less commonly high pressure water hoses.

Inspections are visual after cleaning. (Note: cleaned area may be as small as 1 square foot per underwater structure and will not exceed 5 square feet (0.4645 square meters) under normal conditions.) Photography through a clear water box works well.

A remotely operated vehicle which performed the following tasks or had the following equipment would do everything the divers do: 1) a light, 2) measured depth of water, 3) a clear water box to enhance photography, 4) cleaning equipment (i.e. a scraper or brush), 5) a video camera.

Typical dive depth is 10 to 15 feet (3.048 to 4.572 meters). One location is 150 feet (45.72 meters) which exceeds the divers capability. A few are up to 100 feet (30.48 meters) which is the divers maximum depth. A 17-foot (5.182 meters) Sea Arc boat is available and a zodiac raft is being considered for purchase, but most dives are made off the bank.

Crew size is three people, the minimum number for safety when diving.

A sonar depth finder mounted on a water ski works well for performing scour inspections with the only problem being it will not measure upstream of the bridge. Scour inspection (measurements of stream bottom) are mainly made to confirm analytical studies. Some cross-section water depth measurements are made using the boat.

Key Points:

The team is open to using an automated device but is not actively seeking one. They are aware of remotely operated vehicles.

The use of an automated device must not increase the time required to perform an inspection. If the time requirement did increase it would be used only in exceptions (e.g. too high a flow rate, or debris).

The use of an automated system would not reduce crew size, because of the possibility that a diver might have to go into the water.

An automated system would not allow the responsibility for performing underwater inspections to be transferred back to the district level, because of the training requirement and the relatively infrequent use which would occur with bridges being inspected only once every 5 years.

Date: August 4, 1993
Name: Bernie Holder
Title: Asst. Resident Engineer
Location: Bonham, District 1, Rural County
Interviewers: Wesley Scott

Flagging:

Thought a robot would avoid public confrontation and not get distracted, but doubted it would be cost effective for short-term specific flagging.

Set-up time: usually daytime only flagging so equipment would be set-up and taken down each day.

Mobility: wants equipment to move down the highway with the operations.

Culvert inspection and cleaning:

They don't do culvert cleaning. They do culvert inspection by looking through the end of the pipe. He would like a cleaning capability.

Drilled shaft inspection:

Can tell pretty well with a mirror, if there is water seeping or walls sluffing off. Uses a tape measure and a plumb bob to determine size and vertical alignment. Can tell a lot about the hole by watching the output of the drill.

A light and a camera would be good for critical holes but they don't occur frequently.

Traffic Cones:

Uses a trailer or pick-up to set cones manually. Does not need a robot since the cones can be set when no cars are coming.

Non-destructive testing of Pavement:

Only occasionally needs information on pavement. Might be useful at the district level. They currently read old plans to determine pavement structure and drill cores for confirmation.

Underwater Inspection:

Never done. Inspect bridges in the dry season. State team would do any inspection they needed.

Traffic Lights:

Crew from Paris changes all the lights. The local crew does not change lights. It is not a particularly dangerous operation. He thought a robot arm from the side of the road might be safer if the traffic would slow down.

Other comments:

Nothing exciting in other areas.

Agreed that the maintenance supervisor was doing the nitty gritty work and should be consulted.

Date: August 4, 1993
Name: Mark Schluter
Title: Area Engineer
Location: Decatur, Wise county, District 2
Interviewers: Wesley Scott

Flagging:

Worried about using a robot. Wanted to try a traffic signal.

Culvert inspection and cleaning:

Drilled shaft inspection:

Traffic Cones:

Non-destructive testing of Pavement:

Underwater Inspection:

Traffic Lights:

Other comments:

Wanted time to think about applications for robots

Date: August 4, 1993
Name: David Heim
Title: Tech 5
Location: Graham, District 3
Interviewer: Wesley Scott

Flagging:

Thought a portable stop light or a portable sign with a message would help maintenance. Had access to a portable sign board. Reduce manpower requirement since the area is short handed.

Culvert inspection and cleaning:

Had tried to address. Culverts become silted. Contractors are bidding very high to clean existing culverts when the culverts are being extended.

Had seen a Vactruck.

Thought there might be a bigger emphasis on culverts with the implementation of the Storm Water Pollution Prevention Plan (SW3P).

Drilled shaft inspection:

Used to do inspections by going into the hole but that is now outlawed. They use a mirror to view the hole. He thought a portable light or video equipment would be useful.

Traffic Cones:

Automated system would be good for maintenance because of the manpower problem.

Non-destructive testing of pavement:

Currently use a thin lift nuclear density gauge which will measure up to 2 inches deep. Other nuclear density gauges require a small hole.

Had been told by the Hot Mix Certification Institute that measuring with nuclear density gauges will be eliminated in the specs. Inspection will be by contractors core drilling and use a ridability test measuring the surface waves of the pavement. Nuclear density gauges will only be used to determine rolling patterns.

Underwater Inspection:

No underwater inspections. All done by a state team.

Traffic Lights:

Use bucket trucks to change bulbs. Traffic is not a big problem at his location. Get people out of traffic.

Other comments:

Wanted mixing equipment in the lab. Did not believe that hand mixing of asphalt gave the same results as mixing with the same proportions in a hot mix plant.

Could potentially use a portable mixer for concrete design.

Date: August 12, 1993
Name: Robert Neel
Title: Asst. Area Engineer
Location: Livingston Residency, District 11, Polk County, Rural Area
Interviewers: Wesley Scott

Flagging:

Thought flagging was the most effective method for his area with low volume high speed traffic. Some type of automation might be good for large volume low speed traffic like Houston. High visibility—must be able to see warning device for hundreds of feet in advance.

Culvert inspection and cleaning:

Don't do cleaning but should. They don't have any equipment to do cleaning.

When they do clean a culvert it is either by flushing using a water truck which takes a long time (i.e. not very effective) or by sending a man into the culvert with a shovel. Approximately 15 percent of all culverts in the area are big enough to use a man.

Some culverts have angle joints (eliminates using a borer).

Was aware of a system that had been used in San Antonio to clean storm sewers. It consisted of a pumper truck which output high pressure water through a self-propelling nozzle which used a forward water jet to clean the culvert and backward water jets to move forward and flush the material out of the pipe. It was expensive. He thought the nozzle was patented.

Drilled shaft inspection:

Not a lot of problems. Most shafts are placed using a slurry because of the high water table.

Traffic Cones:

Mainly a contractor problem.

Non-destructive testing of Pavement:

Measure base and some asphalt. Uses a nuclear density gauge takes approximately 15 to 20 minutes per sample.

After description of potential jeep mounted ground penetrating radar, can't justify for area maybe for district.

Underwater Inspection:

Divers from the bridge section in Austin do the inspections. They sometimes use a boat and probe the bottom

Traffic Lights:

Has 20 signal lights in town and 15 to 20 flashing lights, no luminaires in the district. Has to replace a bulb about twice a week. Main cause is the traffic head has been hit causing a hot filament to break. Sometimes have to replace the head or do repairs on it.

Other comments:

Add moving concrete traffic barriers. From his urban experience they sometimes had to move miles of barriers across a lane of traffic in a day. It takes a lot of time to move barriers using a crane. Had heard of some technique where the barriers were connected with hinges to make moving them easier.

Date: August 12, 1993
Name: Bill Garder
Title: Asst. Resident Engineer
Location: Wise County, District 2
Interviewers: Wesley Scott

Flagging:

Absolutely thought using a motorized mannequin was a bad idea. Had lived in a location where it had been tried using a 7/8 scale human figure standing on a 10 inch platform (total height 6 feet). It was kidnapped after 3 days and never returned. Could not remember what location or state where this had occurred.

Office has mentioned using traffic lights, but there is some problem of which he was not aware.

Culvert inspection and cleaning:

Maintenance is managed centrally out of Ft Worth. Believed culverts were cleaned on an exception basis. Said Carl Klose was the person to talk to but he was on leave.

Drilled shaft inspection:

Holes fill with water. Often pouring concrete into water. Any equipment would need to swim.

Contractors have locally-manufactured equipment to check holes.

You can tell if there is a problem by the amount of concrete it takes to fill the hole.

Traffic Cones:

They don't do any construction, just planning, design and oversight of contractors.

Non-destructive testing of Pavement:

Thought nuclear density testing was satisfactory.

Pavement testing is going to a test of the final product rather than all the ingredients.

Smoothness testing needs to be done on the entire length and each lane.

Underwater Inspection:

Recommended contacting the Navy Civil Engineering Lab (NCEL), Port Hueneme, California. "They wrote the book" on underwater construction.

Traffic Lights: Don't do.

Other comments:

Joint replacement in roadways. He had seen an article about a robot which removed the old joint, cleaned the area and installed a new joint.

Add: install reflective buttons on the center line.

Add: remove survey crew from center line.

A large amount of striping is done by the state. Ft Worth definitely does striping.

Date: August 12, 1993
Name: Wes
Title: Maintenance Foreman (??)
Location: Oldham County Maintenance, includes IH 40
Interviewers: Wesley Scott

Flagging:

Definitely does not want an automated flagging device. Arrow boards are okay.

Culvert inspection and cleaning:

Inspect culverts under IH 40 by walking in part way if they are big enough. A crawler with a video camera would maybe work. Main problem is silt.

Drilled shaft inspection:

Doesn't do drilled shaft inspection, did not know who did.

Traffic Cones:

Do extensive traffic cone placement. His people don't like putting cones out because of the danger of being close to traffic.

Non-destructive testing of Pavement:

Engineers do this.

Underwater Inspection:

NO water.

Traffic Lights:

One signal always flashing. No lights on the interstate. Does not apply to him.

Other comments:

None

Persons Interviewed:	Bill Neeley
Topics:	NDT of Roadway Density During Construction
Date:	June 28, 1993
Location:	Camp Hubbard, Building 5
Interviewers:	Tom Yarbrough, Don Maxwell, Walter Boles

Discussion:
A roller-mounted density testing machine exists. We should find out how well it works. Ground penetrating radar is also being developed. Density is usually measured for subgrade materials and air voids are usually measured for asphalt. Nuclear devices are currently used for both subgrade and asphalt. For soils, a hole must be drilled for a probe to make the measurements. A thin-lift gauge is used for asphalt that requires no hole in the material. These are spot measurements--not continuous measurements. Something with a continuous, smooth motion with more coverage is desirable.

Another problem is measuring concrete pavement thickness. Currently, cores are drilled every 1,000 feet to accurately measure pavement thickness. This is very time consuming and requires expensive equipment. If a device could be made to accurately and non-destructively measure concrete pavement thickness easily and more completely, it could be very helpful. We should talk to Ken Stokoe at The University of Texas. He has done some work in this area with geophones. We might also check out the potential of ultrasonic devices.

We should also consider how to get any of the devices we come up with into the field for testing. Before new methods are adopted, they must be proven in the field. This may mean conducting both the current and the new methods simultaneously for one or two years and comparing the results and reliability. This would allow the new methods to gain acceptance prove their worth.

We also briefly discussed profilometers and Mr. Neeley suggested that we see Ken Fults and review the operation of their equipment.

Key Points:
1. We should check out existing machines and research: Geophone work (UT), Ground penetrating radar (TTI), Roller mounted devices (?), visit Ken Fults.

2. We should consider verification and implementation methods—run in parallel with existing?

3. Must be able to duplicate (or exceed) current accuracy of +/- 1/4 inch (6 centimeters) at any one location.

4. Should cost less than two drilling rigs, say $150,000.

Persons Interviewed:	Vernon C. Harris Jr.
Topics:	Culvert Clean Out and Inspection, Drilled Shaft Inspection
Date:	June 29, 1993
Location:	TxDOT, Austin, Bldg. 150, Riverside Drive
Interviewers:	Tom Yarbrough, Don Maxwell, Walter Boles

Discussion:
Cleaning out culverts involves loosening and removing debris from blocked culverts. The blocking material may consist of anything, such as silt, brush, leaves, rocks, household trash, plastic containers, ice chests, and paint cans. Live roots are not usually a problem in roadway culverts but may be in storm sewers. The culvert may have collapsed for a number of reasons.

Culverts are currently cleaned out by hand and by pulling objects through it with cables or steel rods. If the culvert is large enough, a person can go in with a shovel and bucket to clean it out. If high pressure water hoses are available, they may be used to flush out the culvert. Water hoses, however, may not be available in most cases and would be of limited use in ponding situations. The culverts are usually replaced when collapse affects drainage or the roadway surface.

The primary problem seems to be small culverts--2 to 4 feet (61 to 122 centimeters) in diameter. Culverts under 2 feet(61 centimeters) in diameter are rarely used in the Austin District. They can be metal or concrete pipe and deep or shallow under fill. Metal culverts are usually circular or oval in shape. Concrete culverts may be circular of rectangular in cross-section.

A problem culvert is usually discovered when the water backs up during rain storms. It is desirable to clean it out as soon as possible so the ponded water can drain. This means that equipment will need to operate in or under water. The culverts are usually blocked toward the inlet side and may have larger debris collected outside the inlet. Culverts may also be blocked when silt settles out for one reason or another.

There should be video or some type of sensing for user control. It would also be desirable to guide or drive the device into the culvert without manually carrying it. The final weight of the machine may preclude carrying it anyway. It could consist of some type of auguring device.
It may be possible to do the inspection at the same time as cleaning. If not, two machines may be required. A hard copy of the inspection results should be collected during inspection. Both visual and other sensor data plus a written report should be generated. Locations of problems in the culvert are required. The required accuracy of the locating any problem, however, is not great. The top of the culvert is where most of the problems should be found and is what is most important to inspect.

A tethered machine is desirable since extracting the machine is required in case of trouble. This may also provide a convenient mode of communications and power transmission. Inspection activities should consist of checking for rust, changing configuration, and collapse. Good quality visual inspection, if possible, would most likely be sufficient. Inspections should also check for holes and joint integrity. It is probably not necessary to check for cavitation since the presence of cracks, holes, or a collapsed culvert are sufficient reasons to replace it.

We should also talk with other people in the field that do the work. Specific suggestions were Terry Jackson, District 14 Area Engineer and people in Bryan.

A good idea is to survey other districts as to the types and sizes of culverts that are problems and how they currently clean them out. We may wish to learn everything we can locally and then send the results to other districts for their comments.

A discussion of drilled shaft inspection was cut short due to time constraints and will be continued at another time. The discussion revealed that slurry displacement is a real problem because one cannot determine the condition of the hole. Drainage in rock is a problem as is determining the location of reinforcement. Also, are the sides and bottom clean? Some shafts are slanted--about 10%. Sufficient methods do not exist to ensure adequate inspection and documentation of the inspection results.

Key Points: Culverts

1. Types of culverts:
   - Corrugated, galvanized steel -- round or oval
   - Concrete -- round or rectangular

2. Sizes that are of concern:
   - Approximately 2 to 4 feet (61 to 122 centimeters)
   - Any small 2 to 4 foot (61 to 122 centimeters) box culverts
   - Oval corrugated metal pipe

3. Operations will often occur in or under water

4. Inspect for: rust, available cross-section, collapse, holes, and joint integrity.

5. Tethered machine is desirable:
   - to retrieve equipment in case of failure
   - to supply power to heavy equipment
   - to remove debris

6. We should check with field people

Key Points: Drilled Shafts

1. Problems include
   - Slurry displacement
   - Drainage in rock
   - Clean sides and bottom
   - Location of reinforcing

2. Some shafts are slanted -- say 10%

3. Additional discussion needed on this topic

Persons Interviewed:	Otis Jones
Topics:	Culvert Clean Out and Inspection,
Date:	August 12, 1993
Location:	TxDOT, Abilene
Interviewers:	Don Maxwell, Walter Boles

Discussion:
The primary purpose of this visit was to discuss culvert clean out and inspection. It appears that arid districts with less vegetation cover have more serious problems with culverts silting up. Mr. Jones confirmed this and gave us a tour of some local areas where culverts are silted up. They now occasionally use high pressure water hoses to flush the silt out of culverts. They also clean out culverts by dragging some device through them.

The culverts are clogged with sand, silt, and some small amount of grass or weeds at the ends. Blow sand is also a problem in some locations. Most of the problems occur in sandy areas with little relief. Access to most culvert ends, therefore, is usually relatively easy. We were able to take some pictures of clogged culverts and a device sometimes used to drag through and clean them out.

We also talked about the other six short list items and found that they are not big problems in the district. One problem was very important to Mr. Jones, however--slow moving work zone safety. Even when using all precautions, they still get hit on an average of about once to twice per year. There should be some more work on improving moving work zone safety.

Key Points: Culverts

- Problem is likely to be important to districts with sandy soil and more arid climate.

- Any device developed should be simple and easy to use.

Persons Interviewed:	Peter N. Smith and William R. (Randy) Cox
Topics:	Underwater Inspection for Scour and Rust
Date:	July 1, 1993
Location:	TxDOT, Riverside Drive, Bldg. 150, Austin
Interviewers:	Don Maxwell, Walter Boles

Discussion:

All underwater inspections are now done manually by divers. Some of the problems encountered by the diving crew are:

- Depth of water (below 100 feet)
- Flow velocity
- Drift Debris
- Black or murky water
- Hazardous polluted water
- Lots of feeling around because of lack of visibility

A boat with a depth finder is now used to determine bottom profile. Access adjacent to structures and fidelity of the readings may be a problem at times.

Since flooding conditions may cause scour and the cavities may subsequently silt in, it is desirable to know density as well as profile. This is usually done by inserting a rod into the silty soil.

TxDOT is now looking at installing permanent devices, either sensor or physical, that will indicate when scour occurs. This is being considered in problematic situations. It is also important to know flow velocities during floods.

There are 25,000 crossings in Texas. Of these, 8,000 are currently identified as having scour potential. One of the current needs are better measurement techniques to enable better analysis and prediction techniques. New technology is also needed to identify the configuration of bridge supporting structures for which no designs are available. This situation exists because some bridges were originally not part of the state system. Some work is now being done using sound waves to determine depth of the structure. This still does not determine the configuration of the structure below ground.

Structure inspection consists of detecting cracks and rust or general structural condition. In coastal situations, the structure must be cleaned of barnacles before inspection occurs. This exposes divers to shark attack.

Any system developed must be portable and able to be carried in a small boat or a van. In some situations it would be desirable to use the device from the bridge deck. In some situations inspectors have to hike long distances down dangerous slopes and inspect supports that are normally in dry locations.

Key Points:

- More-accurate instruments for data collection are needed
    1. profile
    2. density
    3. rust
    4. cracks

- Remote controlled submersibles with adequate sensory devices will enhance safety

- Any such device must be small and portable

- Visual inspection is desirable but not always possible

Persons Interviewed:	Lewis Rhodes
Topics:	Traffic Flagging, Cones, Bulb Replacement, Paint Striping at Intersections
Date:	July 1, 1993
Location:	TxDOT, Bldg. 150, Riverside Drive, Austin
Interviewers:	Don Maxwell, Walter Boles

Discussion:

Flagging

Automation of traffic flagging operations has been tried many times and failed. There are two principle obstacles to overcome: the complexity of setting up an automated flagging system and the fact that some people have little respect for "machines telling them what to do." For the average maintenance crew, it seems easier to send two people (sometimes viewed as otherwise unproductive members of the crew) to do the flagging rather than to set up what they consider to be a complex system. Even though flagging is one of the most dangerous activities, it is difficult to get workers to use automated systems.

The principle problem, however, is that people do not respect machines and will many times proceed even though they know they should not. They respect a human worker because they know they will be caught. They think they can get away with it if it is only a machine monitoring them. The problem is a human behavioral problem and not a technology problem, since several "off the shelf" systems are available for use.

Many automated systems have been used in the past. One that seems the best is one based upon mobile traffic lights. This system works well at first. As time passes, however, the motorist tend to ignore the system because of the "respect" problem noted above.
It appears that if people know that they will be caught and ticketed, they will obey the system's directions. Systems such as "photo radar" have been used. There are two problems with this--people resent them for reasons of privacy and they destroy the systems. If such systems are to work, a law should be passed to allow for the identification of the driver. This problem appears to be essentially a human problem and not a technology problem.

Cones

Traffic cone placement and retrieval machines do exist. The problem is that it is still cheaper to do it with low paid workers. It is also dangerous. Before automated machines will be used, however, it will have to be mandated by law.

Bulb Replacement

This is a good idea. It may be more complex than expected. There are several things that must be done when servicing traffic lights: remove and clean the lenses, remove and replace the bulbs, clean out the weep holes, and clean the reflector. Sometimes the bulb is broken and is difficult to remove. Even though traffic lights are generally similar, different attaching methods, placement of screws, and other minor differences may make it a very challenging job for an automated machine.

Due to traffic control requirements, taking longer than 20 minutes to do the job requires special traffic control precautions. This is a routine maintenance problem. It is scheduled to be done every 2 years. Emergency replacement occurs much less frequently.

Painting at Intersections

Paint striping and lettering at intersections is a real problem and may be more readily amenable and cost effective for automation. We now use the same costly machines to do it as we do on long simple runs. This is a dangerous job and requires experienced people. No two intersections are alike and people with knowledge and judgment are required to do the job. It requires 2 to 3 people and several support vehicles. It would be nice to have a small device that would fit in or could be towed by a pickup truck and teleoperated to do the painting job. This would be much safer. It may also be possible to integrate some degree of autonomy into the system so the operator is really a planner and supervisor and not depended upon to direct the machine to make every simple move or action. The operator should be able to monitor progress and intervene by observing video feedback from a control station within the truck.

Key Points:

1. Traffic flagging is essentially a human behavior problem
    - A law should be passed to allow for the identification of vehicle drivers
    - Combinations of existing equipment and humans could be used to mitigate hazards.

2. Machines for automatic placement and retrieval of traffic cones exist
    - It is still easier and less expensive to place traffic cones with a pickup truck and two laborers even if it is dangerous
    - It will likely require legislation to mandate the use of cone machines for safety reasons

3. Maintenance of traffic lights is a good idea but may be unfeasible for the near future
    - The application is not robot friendly with respect to mobility
    - Might be an application of an "artificial arm/hand" type of robot.

4. Painting at intersections is an application that has high potential for automation.
    - The device should be small enough to be towed by or hauled by a pickup truck
    - The control station should be incorporated with the truck
    - Hazards to operators could be eliminated and efficiency increased.

Texas Telephone Questionnaire

Person:	Mike Chetty District: 6
Title:	Resident Engineer
Date:	8/18/93 Telephone Number: (915) 684-4981
Location:	Midland
Topic:	Automation in Construction
Interviewer:	Richard M. Gallegos

Discussion:

Flagging for traffic control:
Not a lot of flagging is done in this area. Traffic control is provided by contractors or by the maintenance division. The maintenance division uses flags. On larger projects they use arrow boards and message signs to help in traffic control. An automated robot would not work in this area because flagmen have flexibility and men have brains and common sense. A remote control paddle mounted on a tripod could work on a one-lane roadway but would not seem to work on a two-lane, two-way highway.

Culvert clean-out and inspection:
Clean-out is done by manual labor with no high pressure water and is also contracted out. The inspection of culverts is still eye-balled. They would use a remote video vehicle but only in certain instances. This vehicle would be hard to implement due to the complexity of some culvert configurations.

Drilled shaft inspection:
Help is needed in this area but it must be cheap. Right now they are looking down the hole from the surface with mirrors off of their pickups. Most of the time this works. Something is definitely needed to inspect the bell footings. They have not sent a man down a shaft in a while, unless there is a critical situation.

Placement of traffic cones:
This is still done manually with men in the back of a pickup which is not good and very dangerous. They do a lot of cone placements in this region but Mike had not heard of the cone wheel. It would be a good idea to come up with a dispenser that would lay down a cone certain distances apart.

Non-destructive testing of roadway density:
Nuclear gauges are very useful although it is spot checked. Some type of continuous reading throughout the roadway would be interesting.

Underwater structure inspection - scour and corrosion:
No problem in this region.

Illumination and Traffic light replacement:
Traffic lights are handled out of the district office. Mike doesn't handle this area directly.

Other areas for automation:
Do not see any areas for automation.

Texas Telephone Questionnaire

Person:	Michelle Kopp District: 15
Title:	Assistant Area Engineer
Date:	8/19/93 Telephone Number: (210) 615-6022
Location:	San Antonio
Topic:	Automation in Construction
Interviewer:	Richard M. Gallegos

Discussion:

Flagging for traffic control:
Usually use flags and have flagmen for certain purposes. A robot would not work to replace a flagman because it is difficult to program into a computer because of the many variables to consider.

Culvert clean-out and inspection:
Clean-out is now done with shovels, bobcats, and in smaller culverts high pressure water is used. Michelle can see some type of scooper to get in and clean culverts some time in the future to be helpful. Inspection is still eye-balled and no video equipment is used except for still pictures.

Drilled shaft inspection:
Inspection is visual from the top, no one is lowered down. Some type of electronic eye dropped down, would be helpful.

Placement of traffic cones:
Still done manually with men in the back of a pickup. Michelle has seen pictures of a cone wheel but they do not have in this residency. The cone wheel would be effective but only in certain situations.

Non-destructive testing of roadway density:
Now done by nuclear gauges. A continuous reading would be good.

Underwater structure inspection - scour and corrosion:
Handled by bridge division in Austin.

Illumination and Traffic light replacement:
Crews are sent out to unscrew the light bulbs. No automation is seen in this area.

Other areas for automation:
Cannot think of anything right now.

Texas Telephone Questionnaire

Person: Patrick U. Norrell District: 16
Title: Resident Engineer
Date: 8/19/93 Telephone Number: (512) 808-2264
Location: Corpus Christi
Topic: Automation in Construction
Interviewer: Richard M. Gallegos

Discussion:

Flagging for traffic control:
Follow a handbook with procedures both in maintenance and in construction. For long term operations message boards and temporary traffic signals work fine.

Culvert clean-out and inspection:
Larger culverts are cleaned manually by contractors. Smaller culverts are washed out and debris is removed by a Vactor truck in maintenance. Inspection of culverts is mainly eyeballed. The inspection of sewer systems uses video equipment provided by the city. This equipment is remote controlled, has lights and has worked great.

Drilled shaft inspection:
They use to lower a man down but this is not done anymore. No video equipment is used, inspection is from the top only because shafts are not very deep. This is a problem that needs to be addressed. If it is too deep to see down, they will not send a man down. For bell footings, contractors supply cameras for inspection.

Placement of traffic cones:
Manually done with a person on the back of a pickup. They start on one side of the roadway holding traffic and then place the cones. No automation is seen in this area although Pat has seen brochures on automation equipment in this area.

Non-destructive testing of roadway density:
Nuclear gauges are now used. This is still dangerous because the person must dig a hole and is exposed to traffic. They must dig holes to check, so a person will always be exposed to traffic.

Underwater structure inspection - scour and corrosion:
Not really involved. It is done mainly by contractors who supply divers and video equipment.

Illumination and Traffic light replacement:

District crews do all of the light replacements. Illuminaires are contracted with a local firm. Crews are in danger because the back of the truck is always exposed. This area does not have much of a problem with collisions.

Other areas for automation:
Surveying, since people are exposed on the roadway and are not protected by cone operations as in construction.

Texas Telephone Questionnaire

Person: James E. Hunt District: 18
Title: Resident Engineer
Date: 8/23/93 Telephone Number: (214) 320-6240
Location: Dallas
Topic: Automation in Construction
Interviewer: Richard M. Gallegos

Discussion:

Flagging for traffic control:
Contractors use flagmen daily. In maintenance, flagmen use flags and walkie talkies and no paddles. This area is very difficult for a robot because a person is needed to react to situations and there is a lot of decision making.

Culvert clean-out and inspection:
They drag a bucket through and use small dozer equipment. They use their own forces or contract out. High pressure water is used to clean inlets only. This would be very difficult for a robot to do, you still need an operator. Inspection is eye-balled in maintenance. In larger culvert construction they will send men in with oxygen tanks. For small pipe culverts, James can see the use for video equipment.

Drilled shaft inspection:
They will lower a man down into every shaft and they do a lot of these. In cased shafts, they use respirators. Bell footings are in every shaft and some shafts are over 100 feet (30.48 meters) deep. Generally, the shafts are 30-50 feet (9 to 15 meters) deep. Video equipment would be very useful in this area.

Placement of traffic cones:
Cones are manually placed now. James would use an automated device if he had one since this is a dangerous procedure.

Non-destructive testing of roadway density:
Nuclear gauges are used. James said automation is coming since NDT on concrete is considered automated. This will allow traffic to drive on concrete highways quicker.

Underwater structure inspection - scour and corrosion:
Not a lot done in this area. Consulted for scour inspection.

Illumination and Traffic light replacement:
Crews in Dallas go out and do.

Other areas for automation: Not any off the top of his head but will call back later.

Texas Telephone Questionnaire

Person: Jerry Armstrong District: 19
Title: Maintenance Construction Supervisor
Date: 8/24/93 Telephone Number: (903) 935-3637
Location: Marshall
Topic: Automation in Construction
Interviewer: Richard M. Gallegos

Discussion:

Flagging for traffic control:
Using flags right now. They use arrow boards when feasible. This area has a lot of farm and market roads so a robot would not be cost efficient.

Culvert clean-out and inspection:
They clean out both ends manually or wash-out. Jerry said there is a machine that is a high-pressure augur that could clean out culverts. They do not have this machine in this area. Clean-out is a continuous job due to the amount of silt in this area. Inspection is eyeballed and no video equipment is used even though it is available.

Drilled shaft inspection:
Not anything to do with that.

Placement of traffic cones:
Men in the back of a pickup on the tail gate. He has seen the cone wheel but for everyday jobs, it would not be beneficial. If they coned all day as on an interstate, it would be helpful.

Non-destructive testing of roadway density:
Not anything to do with that.

Underwater structure inspection - scour and corrosion:
Not anything to do with that.

Illumination and Traffic light replacement:
Handled by the district. Traffic lights are replaced by crews and they also cut limbs.

Other areas for automation:
Not any that he is aware of.

Texas Telephone Questionnaire

Person: Salsido Ramirez District: 21
Title: Maintenance Foreman
Date: 8/23/93 Telephone Number: (210) 542-2260
Location: Brownsville
Topic: Automation in Construction
Interviewer: Richard M. Gallegos

Discussion:

Flagging for traffic control:
Use both flags and paddles in this area. Some trucks have mounted flags on them. Automated techniques would include an arrow board on long term jobs. Flagmen are used on small jobs such as patching. The industrial shop has modified a message board to be a neon sign with a computer. There is not much of a problem with flagging in this area because not much is done.

Culvert clean-out and inspection:
For pipe culverts, the ends are cleaned out and a cable is run through the other side and tires are placed on this side and ran through the culvert to clean-out. Larger culverts are not cleaned out because there is not much of a problem, they just clean the ends. Inspection is sometimes done usually when a complaint comes in. Video equipment would help with determining cracks from the inside. Salsido has seen a machine like an augur that cleans out culverts but it is not in this district.

Drilled shaft inspection:
Not done in this area.

Placement of traffic cones:
Manually with men on the back of a truck and to pick up the cones, they go backwards. He has seen a machine that picks up small 12 in cones and he thinks it is the cone wheel, but none are in this district.

Non-destructive testing of roadway density:
None in maintenance but in the residency level.

Underwater structure inspection - scour and corrosion:
No underwater inspection is done, just look at what is above the water line.

Illumination and Traffic light replacement:
Signal light, light bulbs, are replaced by maintenance and the residency repairs major work needed on signals.

Other areas for automation:
Surveying is something needed to be automated. He mentioned a brush cleaner (that the SHRP personnel has made) to clean around signs . He's trying to acquire a portable augur to install signs. He mentioned a litter pickup truck that you drive around to pick up litter, which worked well.

APPENDIX F

INTERVIEWS WITH OTHER STATES

Alabama

Talked with and contributed to the seven items.	Others

Pete Anderson - Road Construction Engineer - (205) 242-6208

Mark Strickland - Assistant Bridge Construction Engineer - (205) 242-6210

Frank L. Holman - Research Engineer - (205) 242-6539

Mike Harper - Maintenance Engineer - (205) 242-6208

Alaska

Talked with and contributed to the seven items.	Others

Howard Jurue - Assistant Quality Control Engineer - (907) 269-6230

John Povar - Technical Engineer - (907) 465-2975

Steve Bradford - State Bridge Engineer - (907) 465-2975

Bill Mowl - Anchorage District Superintendent - (907) 333-2411

Arizona

Talked with and contributed to the seven items.	Others

A. Wayne Collins - Assistant State Maintenance Engineer - (602) 255-7410

Dick Berusch - Structures Engineer - (602) 255-7481

George Way - Pavement Services Engineer - (602) 255-8085

Richard Gentemam - District Engineer - (602) 255-7323

Ron Williams - Construction Engineer - (602) 255-7120

Arkansas

Talked with and contributed to the seven items.	Others
Pat Sullivan - Staff Construction, Maintenance Engineer - (501) 569-2251	Allan Holmes - Engineer of Construction and Maintenance - (501) 569-2251
	Bill Muholland - State Maintenance Engineer - (501) 569-2251

California

Talked with and contributed to the seven items.	Others
Allan Wells - Office Chief Division of Maintenance - (916) 654-5849	Richard Dills - Senior Bridge Engineer - (916) 227-8229
Jim MacFarlane - Materials and Research Engineer Assistant - (916) 227-7000	
Carl Harris - Office of Maintenance - (916) 227-8841	

Colorado

Talked with and contributed to the seven items.	Others
Bruce Benson - Engineering Technician II - (303) 757-9272	Douglas L. Shaffer - Director, Maintenance and Operations - (303) 757-9203
Chuck Loerwald - Maintenance Manager, Coordinator - (303) 757-9536	
Walt Mistkowski - Bridge Inspection Engineer - (303) 757-9338	
Charlie MacKeen - Engineer B - (303) 757-9249	

Connecticut

Talked with and contributed to the seven items.	Others
Donald Larson - Research Engineer - (203) 258-0372	Charles E. Dougan - Research & Materials - (203) 258-0372
Mike Turano - Highway Operation Superintendent - (203) 566-8365	Louis R. Malerba - Maintenance Operations - (203) 566-8365
George Pfuetzner - Maintenance, Traffic Light Replacement - (203) 258-0351	John Maculi - Traffic Services Engineer - (203) 258-0351
	Steve Cage - Lab Technician - (203) 258-0327

Delaware

Talked with and contributed to the seven items.	Others
Raymond Pusey - Director, Division of Highways - (302) 739-4361	Glenn Bell - Physical Plant, Maintenance Superintendent II - (302) 739-4611
Dennis Ho - Central District Engineer - (302) 739-4219	

Florida

Talked with and contributed to the seven items.	Others

Jack Brown - State Traffic Operations Engineer - (904) 488-4284

Marshall Stivers - State Maintenance Engineer - (904) 488-8814

Peter Lai - Assistant State Geotechnical Engineer - (904) 488-6351

Frank Daves - (904) 488-8814

Paul Passey - State Geotechnical Engineer - (904) 488-6351

Bob Nickels - Engineer of Structural Design - (904) 488-6351

John Harris - Traffic Services Engineer - (904) 488-8814

Bob Ho - Soils and Materials Engineer - (904) 372-5304

Georgia

Talked with and contributed to the seven items.	Others

Larry Seabrook - State Maintenance Engineer - (404) 656-5314

Charles Evans - (404) 656-5314

Steve Henry - (404) 656-5314

Larry S. - (404) 656-5314

Hawaii

Talked with and contributed to the seven items.	Others

Don Arnales - Bridge Engineer - (808) 587-2206

Idaho

Talked with and contributed to the seven items.	Others

Clayton Sullivan - Maintenance Supervisor - (208) 334-8405

Illinois

Talked with and contributed to the seven items.	Others

Jim Easterly - Construction Engineer - (217) 782-6667

Todd Aarons - Engineer of Structural Services, Bureau of Bridge and Structures - (217) 782-2124

Bill Kramer - Senior Geotechnical Engineer - (217) 782-7773

Allan Goodfield - Geologist - (217) 782-7773

Eric Harm - (217) 782-7200

James G. Gehler - Chief of Materials and Research - (217) 782-7200

Bill Flanagan - Bridge Engineer - (217) 782-4503

Emil Samara - Foundations - (217) 782-7773

Indiana

Talked with and contributed to the seven items.	Others

Dave Ward - Section Engineer Supervisor - (317) 463-1521

Barry Partridge - Chief of Division of Research - (317) 463-1521

Iowa

Talked with and contributed to the seven items.	Others
Tim Crouch - Traffic Control Engineer - (515) 239-1519	Will Zitterich - (515) 239-1396
Jim Rost - Geotech - (515) 239-1352	Burny Brown - State Materials Engineer - (515) 239-1600
Dwight Rorholm - Maintenance Operations Engineer - (515) 239-1589	Tom Crackler - Director, Construction Division - (515) 239-1503
Tim Dunley - Assistant Head Engineer, Bridge maintenance - (515) 239-1206	John Smice - Assistant for Construction Division - (515) 239-1503
Dwight Steven - State Traffic Engineer - (515) 239-1513	
Jerry Bergren - Assistant State Materials Engineer - (515) 239-1352	

Kansas

Talked with and contributed to the seven items.	Others
Dean Testa - Chief of Construction and Maintenance - (913) 296-3576	

Kentucky

Talked with and contributed to the seven items.	Others
Bill Crace - Director, Division of Maintenance - (502) 564-4556	Paul Gravely - Director, Division of Construction - (502) 564-4780
Jim Burchett - Construction Engineer - (502) 564-4555	Henry Mathes - Geotechnical Engineer - (502) 564-2374
Daryl Greer - Traffic Engineer II - (502) 564-2374	Roland Risenburg - (502) 564-4555
John Renfro - Electrical Engineer - (502) 564-3020	Simon Cornett - Director, Division of Traffic - (502) 564-3020

Louisiana

Talked with and contributed to the seven items.	Others
Gill Gaustreau - Bridge Maintenance Structural Engineer - (504) 379-1551	Tommy Bergeron - District Construction Engineer - (504) 231-4103
Bill Hickey - Road Design Engineer - (504) 379-1303	Frank Castjohn - (504) 379-1551
Wayne Amen - Bridge Design Engineer - (504) 379-1332	Joe Smith - Maintenance Engineer - (504) 379-1551
Francis Becnel - Traffic Services Engineer - (504) 935-0101	

Maine

Talked with and contributed to the seven items.	Others
Gary Maines - Assistant Highway Maintenance Engineer - (207) 287-2661	Bryan Pickard - Highway Maintenance Engineer - (207) 287-2661
Richard Weeks - Pavement Management - (207) 287-5556	
Ed King - Traffic Engineer - (207) 287-3775	
Gary Hoer - Bridge Maintenance - (207) 287-2729	

Maryland

Talked with and contributed to the seven items.	Others
John Scally - Assistant Deputy Chief, Engineering Maintenance - (410) 859-7363	Sam Miller - Chief Engineering Materials and Research - (410) 321-3541
Joe Miller - Chief of Bridge Repair - (410) 333-1175	Dave Logan - Group Leader, Bridge Inspection - (410) 333-1175
Paul Perkins - Assistant Chief Engineer - (410) 333-1169	
Ray Dotterweich - Assistant Deputy Chief, Materials and Research - (410) 321-3541	

Massachusetts

Talked with and contributed to the seven items.	Others
Chuck Sterling III - State Traffic Engineer - (617) 973-7360	
Tony Petronio - Maintenance Engineer - (617) 973-7740	
Paul Mardone - Bridge Inspection Engineer - (617) 973-7570	
Leo Stevens - Material and Research Engineer - (617) 235-6100	

Michigan

Talked with and contributed to the seven items.	Others
Gerald D. Dobie - Construction Engineer - (517) 373-2300	

Mississippi

Talked with and contributed to the seven items.	Others
Bob Denson - Pavement Engineer, Research Department - (601) 359-1174	Richard Young - Traffic Control and Safety Engineer - (601) 354-6050
Gary Hillman - Asssistant State Maintenance Engineer - (601) 359-1145	Bob Mosely - State Maintenance Engineer - (601) 359-1145
John Taylor - Rating and Inspection Engineer - (601) 359-1181	B.J. Logan - (601) 354-6358
Bob Mayprey - State Traffic Engineer - (601) 944-9333	Richard N. - (601) 359-1181
	Doug Funchuss - (601) 359-1000

Missouri

Talked with and contributed to the seven items.	Others
Jim Jackson - Division Engineer, Maintenance and Traffic - (314) 751-2785	

Minnesota

Talked with and contributed to the seven items.	Others
Merritt H. Linzie - Director of Highway Programs - (612) 296-1638	John Howard - Maintenance Standards and Operations Engineer - (612) 297-3593
John Jackels - (612) 269-2721	Rod Plateon - Maintenance Engineer - (612) 297-3590
Greg Felt - Equipment Engineer - (612) 725-2354	
Don Augerman - (612) 296-0862	
Don Fleming - State Bridge Engineer - (612) 296-3172	

Montana

Talked with and contributed to the seven items.	Others
William S. Strizich - Bureau Chief of Maintenance and Equipment - (406) 444-6158	

Nebraska

Talked with and contributed to the seven items.	Others
Dan Wattle - Signing and Marking Engineer - (402) 479-4594	Lyman D. Freeman - Bridge Division Engineer - (402) 479-4701
Rolly Heedum - Highway Maintenance Manager - (402) 479-4542	Kenneth J. Gottula - Engineer, Traffic Engineering Division - (402) 479-4594
Mark Traiynowitz - Geotechnical Engineering - (402) 479-4701	
Osvald Bumanis - Bridge Division Engineer - (402) 479-4701	
George Wilstrom - Special Project Engineer - (402) 479-4791	
Bob Wedner - Materials Engineer - (402) 479-4707	

Nevada

Talked with and contributed to the seven items.	Others
Bill Darby - Assistance Maintenance Division - (702) 687-5615	Frank Taylor - Maintenance - (702) 687-5615
Dave Cochran - Highway Engineer IV - (702) 687-5520	
Floyd Macusy - Bridge Division Chief - (702) 687-5525	

New Hampshire

Talked with and contributed to the seven items.	Others
Jim County - Pavement Monitoring, Team Leader - (603) 271-2291	Robert Hogan - State Maintenance Engineer - (603) 271-2693
Dean Bennett - Chief Bridge Inspector - (603) 271-3667	Jim Colburn - Traffic Engineer - (603) 271-2291
Perley Sherrette - Traffic Signal Technician - (603) 271-2291	Harvey Goodwin - Administrator - (603) 271-3667
Allan Perkins - Chief of Materials Technology - (603) 271-3151	Paul Matthews - (603) 271-3151

New Jersey

Talked with and contributed to the seven items.	Others
Robert Scancella - Project Engineer, Bureau of Maintenance - (609) 292-4908	Jim Rush - Manager of Construction - (609) 530-2591
Larry Sroka - Electrical Project Engineer - (609) 530-3725	Michael B. Kjetsaa - Director of Construction and Maintenance - (609) 530-2591
John Pezik - Project Engineer in Maintenance - (609) 530-3858	Henry Justice - Bureau of Maintenance - (609) 530-2307
	Lee Steiner - State Traffic Engineer - (908) 308-4077
	I. B. Senyk - Maintenance Engineer - (609) 530-2702

New Mexico

Talked with and contributed to the seven items.	Others
Stanley Griego - Chief of Maintenance and Traffic Services Bureau - (505) 827-5525	

New York

Talked with and contributed to the seven items.	Others
Bob Valenti - Assistant Director in Engineering Research - (518) 457-5826	Dr. Robert J. Perry - Engineering Research and Development - (518) 457-5826
Barkley Berry - Director, Maintenance Division - (518) 457-6435	Kenneth W. Shiatte - Maintenance Division- (518) 457-6435
	Jim Briddon - (518) 457-3225
Perry Cooper - Civil Engineer III, Traffic - (518) 457-6438	Thomas C. Werner - Traffic Engineering and Safety Division - (518) 457-6438

North Carolina

Talked with and contributed to the seven items.	Others

Nari Abar - Soils Engineer - (919) 250-4128

Shane Wu - Assistant State Pavement Management Engineer - (919) 250-4094

Jesse Gilstrap - Traffic Control Design Engineer - (919) 250-4159

Don Idol - Assistant Bridge Inspection Engineer - (919) 733-4362

Milton Dean - Signals Manager Engineer - (919) 733-3915

Glenn Williams - Bridge Inspection Supervisor - (919) 733-4362

Jim Kellenberger - Traffic Control Project Engineer - (919) 250-4159

David Allsbruck - Assistant Unit Head of Maintenance - (919) 733-3725

John Leadbetter - (919) 250-4128

Jerry Linder - County Maintenance Engineer - (919) 733-4768

Frank Pace - State Road Maintenance Engineer - (919) 733-3725

James D. Lee - Bridge Maintenance Unit Head - (919) 733-4362

North Dakota

Talked with and contributed to the seven items.	Others

John Bjorke - Maintenance Engineer - (701) 224-4425

Jerry Horner - Assistant Maintenance Engineer - (701) 224-4425

Ohio

Talked with and contributed to the seven items.	Others
Keith C. Swearingen - Engineer, Bureau of Maintenance - (614) 466-3264	Floyd Cox - District Bridge Engineer - (419) 281-0513
Jon Wackerly - Assistant Structural and Inspection Engineer - (614) 466-3893	
Rick Ingle - Assistant Engineer of Bridges - (614) 466-3893	

Oklahoma

Talked with and contributed to the seven items.	Others
David Golden - Maintenance Division Manager - (405) 521-2557	

Oregon

Talked with and contributed to the seven items.	Others
Wayne Cobine - Operations Manager for Construction , Maintenance and Materials - (503) 378-6528	William Anhorn - State Highway Engineer - (503) 378-6388

Pennsylvania

Talked with and contributed to the seven items.	Others
Gary L. Hoffman - Director, Bureau of Maintenance and Operations - (717) 787-6899	Rick Sesny - Traffic Engineering Division - (717) 783-6080

Rhode Island

Talked with and contributed to the seven items.	Others
John D. Nickelson - Chief Civil Engineer - (401) 277-2378	

South Carolina

Talked with and contributed to the seven items.	Others
Jim Bennett - Civil Engineer II- (803) 737-1459	McRaney Fulmer - Director of Maintenance - (803) 737-1290
Hulley Shumpert - Assistant State Maintenance Engineer - (803) 737-1290	
Lee Floyd - Bridge Inspection Engineer - (803) 737-1490	
Dave Louis - Bridge Engineer - (803) 737-1490	
Charles L. Matthews - Bridge Engineer, Construction - (803) 737-1490	

South Dakota

Talked with and contributed to the seven items.	Others
Norm Humphrey - State Maintenance Engineer - (605) 773-3571	Rich Phillips - Head of Hydraulics - (605) 773-3285
Mike Durick - State Construction Engineer - (605) 773-3571	
Gill Hadman - Pavement Design Engineer - (605) 773-3401	

Tennessee

Talked with and contributed to the seven items.	Others

Carl Cobble - Civil Engineer Manager II - (615) 741-2027

Mark Harland - Structures Engineer - (615) 741-3351

Jim Norris - Civil Engineer Director, Maintenance - (615) 741-2027

John Garland - head of Construction Division - (615) 741-3408

Utah

Talked with and contributed to the seven items.	Others

Boyd Fronk - Supervisor Division II - (801) 975-4952

Gerald Barrett - Engineer for Maintenance - (801) 965-4114

Vermont

Talked with and contributed to the seven items.	Others

Milan W. Lawson - Maintenance Engineer - (802) 828-2587

Virginia

Talked with and contributed to the seven items.	Others

Woody Woodward - Assistant Maintenance Division Administrator - (804) 786-2847

Lynwood Butner - State Traffic Engineer - (804) 786-2965

Mal Kerly - State Bridge Engineer - (804) 786-2635

Richard Steel - Assistant State Materials Engineer - (804) 328-3102

Walt Hayden - State Materials Engineer - (804) 328-3102

Bob Horand - Materials Engineer - (804) 328-3102

Andrew V. Bailey - Maintenance Engineer - (804) 786-2847

Washington

Talked with and contributed to the seven items.	Others
Dave Bauers - Road Maintenance Engineer - (206) 705-7862	Bob George - Supervisor, Bridge Maintenance - (206) 753-4739
Mike Nesbitt - Traffic Control Engineer - (206) 705-7293	Dave Peach - State Traffic Engineer - (206) 705-7280
Jerry Wigel - Construction Engineer - (206) 705-7825	John Conrad - Chief Maintenance Engineer - (206) 705-7851
Charles Ruth - Bridge Construction Engineer - (206) 705-7825	
Hugh Favero - Senior Bridge Condition Engineer - (206) 753-4739	
Dean Lokken - Electrical Engineer - (206) 753-2187	

West Virginia

Talked with and contributed to the seven items.	Others
Jim Riggs - Regional Engineer - (304) 558-2901	Julian Ware - Acting Director, Maintenance Division - (304) 558-2901

Wisconsin

Talked with and contributed to the seven items.	Others
Dave Vieph - Chief of Programs for Highway Maintenance Office - (608) 266-7594	Mike Cass - State Maintenance Engineers for Highways - (608) 266-7594
Bob Anderdorfer - Geotech - (608) 246-7940	Phil Decabooter - Pavement Management - (608) 246-7955
Bill Ducket - Pavement Management Engineer - (608) 246-7955	

Wyoming

Talked with and contributed to the seven items.	Others
Ken Shultz - Maintenance Staff Engineer - (307) 777-4459	Richard R. Stapp - State Construction and Maintenance Engineer - (307)777-4456

Telephone Questionnaire

Person: Thomas B. Dean State: Washington D.C.
Title: Transportation Research Board - Executive Director
Date: 6/28/93 Telephone Number: (202)334-2936
Topic: Robotics and Automation in Construction
Interviewer: Richard M. Gallegos

Discussion: Thomas Dean was in a meeting so I was connected with the librarian who said to talk with Sandi Tucker at TTI about doing a search in TRIS database. This particular database contains what the TRB has accomplished to date.

If more information is needed, contact the construction engineer Fred Hejl @ 1-800-424-9818 ex. 2952 after July 8, 1993.

Telephone Questionnaire

Person:	Robert J. Reilly	State: Washington D.C.
Title:	Program Director of National Cooperative Highway Research program	
Date:	6/28/93 Telephone Number: (202) 334-3224	
Topic:	Robotics & Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion: Robert was in a meeting but the secretary recommended the TRIS database.

Telephone Questionnaire

Person: Amy Steiner State: Washington D.C.
Title: Standing Committee on Highways - AASHTO Staff Liaison
Date: 6/28/93 Telephone Number: (202) 624-5800
Topic: Robotics and Automation in Construction
Interviewer: Richard M. Gallegos

Discussion: Amy did not know of any research that was going on in this committee. She referred to the librarian, Joan Cahoke at the same phone number, for more information.

Need to call Joan back for more information.

Telephone Questionnaire

Person: Jim Easterly State: Illinois DOT
Title: Construction Engineer
Date: 6/28/93 Telephone Number: (217) 782-6667
Topic: Robotics and Automation in Construction
Interviewer: Richard M. Gallegos

Discussion:

Flagging for traffic control: Referred to Eric Harm, Maintenance Engineer (217) 782-7200. Eric on next page.

Culvert clean-out and inspection: Use a high pressure hose to clean-out and human visual inspection. Consulting firms or contractors usually do the job not the state. He has seen some consulting firms using video equipment for inspection.

Drilled shaft inspection: Said that this was not really done in Illinois.

Placement of traffic cones: This state still does this manually. California has a TTV machine that puts up and moves concrete barriers automatically.

Non-destructive testing of roadway density: Nuclear gages are used, hand held or driven but not fully automated.

Underwater structure inspection - scour and corrosion: Rarely done but they use divers. No video equipment used or planned to be used.

Illumination and Traffic light replacement: Still done manually but some lighting systems are solar power.

** Jim said he was going to call back to expound on these areas but still no response to date. The state was not looking into robotizing any of these tasks.

Telephone Questionnaire

Person:	Eric Harm	State: Illinois DOT
Title:	Maintenance Engineer	
Date:	6/29/93	Telephone Number: (217) 782-7200
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion: Eric reiterated what Jim easterly had said.

Flagging for traffic control: Still done manually but for long-term construction they use automatic traffic lights.

Culvert clean-out and inspection: When the state does clean-out culverts its by a high pressure water hose. Inspection by the state is simply looking at the ends.

Drilled shaft inspection: Not really done. Bill Kramer, Senior Geotech Engineer, said that the state was just starting into this area. They may lower a man down if needed, but video equipment is not used. They will contract this area if inspection takes place underwater.

Placement of traffic cones: All manually done - pick up and put down.

Non-destructive testing of roadway density: nuclear gages are used.

Underwater structure inspection - scour and corrosion: Divers are used. Todd Aarons, Engineer of Structural Services, Bureau of Bridges and Structures, said that they contract out, or wade through the water, probing. They also use sonar to profile the river bottom.

Illumination and Traffic light replacement: Still manually replaced.

Telephone Questionnaire

Person:	Dave Ward	State: Indiana DOT
Title:	Section Engineer Supervisor	
Date:	7/2/93	Telephone Number: (317) 463-1521
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: IDOT obeys federal guidelines pertaining to flagging. Usually it is manually done. There is research in SHRP reports about a paddle with strobe lights attached. There is no automation in IDOT for this area.

Culvert clean-out and inspection: Jet trucks usually clean-out with water. Inspection is done by eye-balling. Purdue University has done a study on a camera mounted on an extension that runs down a culvert to inspect, this information is found on the TRIS database.

Drilled shaft inspection: Very seldom done but men are lowered down to inspect. No video equipment is used nor is there research planned in this area.

Placement of traffic cones: Usually manually done by the state. When contractors are used on the project then they do what ever they want.

Non-destructive testing of roadway density: On asphalt they use nuclear gages, portable Troxler. Concrete they use core samples.

Underwater structure inspection - scour and corrosion: Not a lot done in this state. If inspection is done in a river then they inspect at the lowest level of the river for a given year, and eye ball it.

Illumination and Traffic light replacement: Done manually.

** Note : Dave read a long list of research items the state of Indiana is doing. None of the items really pertained to the above subject matter.

Telephone Questionnaire

Person:	Donald Larson	State: Connecticut DOT
Title:	Research Engineer	
Date:	6/30/93	Telephone Number: (203) 258-0372
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Manually done. He is looking into lighted paddles, the article is in the SHRP videos and catalog. He also said New York county is using alternating traffic signals.

Culvert clean-out and inspection: Rarely done but if done they have a machine (VACTOR) that sucks up the waste.

Drilled shaft inspection: Do not really do.

Placement of traffic cones: Manually done. He did mention a Cone wheel that picks up and places the cones but was unsure if it really worked. No plans for any automation.

Non-destructive testing of roadway density: Done by nuclear gages -Troxler.

Underwater structure inspection - scour and corrosion: Mike Turano, next page;

Illumination and Traffic light replacement: Manually done.

Telephone Questionnaire

Person:	Mike Turano	State: Connecticut DOT
Title:	Highway Operation Superintendent	
Date:	7/2/93	Telephone Number: (203) 566-8365
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control:

Culvert clean-out and inspection: They sometimes use the VACTOR, and they also have a manual machine called the Orange Peeler that cleans by using a scoop or a clamp. All manually inspected with no video equipment.

Drilled shaft inspection: none done.

Placement of traffic cones:

Non-destructive testing of roadway density: Nuclear gages are used. No research is planned in this area.

Underwater structure inspection - scour and corrosion: They use divers with no video equipment.

Illumination and Traffic light replacement: Government contracts for replacement but still all manual. No research planned in this area.

Telephone Questionnaire

Person:	Bob Valenti	State: New York DOT
Title:	Assistant Director in Engineering Research	
Date:	7/2/93	Telephone Number: (518) 457-5826
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: When the state does then it is manually done. Contractors are used in some cases and they do whatever they want. No research planned in this area. Refer to Perry Copper.

Culvert clean-out and inspection: No video inspection. Refer to Barkley Berry.

Drilled shaft inspection: No drilled shaft inspections done.

Placement of traffic cones: MUTCD requirements are followed by manual means. Nothing out of the ordinary is used. Refer to Perry Cooper.

Non-destructive testing of roadway density: Nuclear gages are used in spot checking.

Underwater structure inspection - scour and corrosion: Use divers with no video equipment.

Illumination and Traffic light replacement: Manually done.

Telephone Questionnaire

Person:	Barkley Berry	State: New York DOT
Title:	Director, Maintenance Engineer	
Date:	7/2/93	Telephone Number: (518) 457-6435
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Perry Copper; Civil Engineer III. Traffic; (518) 457-5826; When the state does, then it is manually done. For longer operations portable traffic signals are used. For bridge repair with one lane open then they use a regular traffic signal. He mentioned a device called Robostop which consists of a stop, slow down paddle sitting on a tripod that is all remote control operated.

Culvert clean-out and inspection: clean-out by water power. Visual manual inspection with no video inspection. No research planned in this area.

Drilled shaft inspection: No drilled shaft inspections done

Placement of traffic cones: Perry Copper; Manually done by men on a truck. He mentioned but it is not used - a Cone wheel.

Non-destructive testing of roadway density: Nuclear gages are used only during construction.

Underwater structure inspection - scour and corrosion: Use divers with no video equipment.

Illumination and Traffic light replacement: Manually done, use power trucks (cherry picker).

Telephone Questionnaire

Person:	Pete Anderson State: Alabama
Title:	Road Construction Engineer
Date:	7/6/93 Telephone Number: (205) 242-6208
Topic:	Robotics and Automation in Construction
Interviewer:	Richard M. Gallegos

Discussion:

Flagging for traffic control: Maintenance done by the state is done manually. When contractors are used sometimes they use temporary signals.

Culvert clean-out and inspection: Inspection is eye-balled except when there is a long small structure, then video is used but this is very rare.

Drilled shaft inspection: Mark Strickland; Assistant Bridge Construction Engineer; (205) 242-6210; If dry then have a man on a sling with no video equipment. If the drilled shaft is wet they take readings by using a plumb bob and a tape measure. They also inspect by the way the augurs come out of the ground.

Placement of traffic cones: Use federal guidelines to spacing. Manually place down cones.

Non-destructive testing of roadway density: Contractors use nuclear gages.

Underwater structure inspection - scour and corrosion: Mark Strickland; Manual, divers feel around but video would not be practical since the water is so dark..

Illumination and Traffic light replacement: Manually done.

Telephone Questionnaire

Person:	Stanley Griego State: New Mexico
Title:	Chief, Maintenance and Traffic Services Bureau
Date:	7/9/93 Telephone Number: (505) 827-5525
Topic:	Robotics and Automation in Construction
Interviewer:	Richard M. Gallegos

Discussion:

Flagging for traffic control: Follow the MUTCD, manually done. They do use stop, slow paddles but the paddles do not light up.

Culvert clean-out and inspection: They either hire a contractor to do the job or they use a VACTOR truck which can either pull a vacuum or can be used as a high pressure hose.

Drilled shaft inspection: not done in New Mexico.

Placement of traffic cones: Manually placed and picked up.

Non-destructive testing of roadway density: Troxler nuclear gages which is still manual.

Underwater structure inspection - scour and corrosion: nothing really underwater in this state.

Illumination and Traffic light replacement: all manually done with no plans to research.

Telephone Questionnaire

Person:	A. Wayne Collins State: Arizona DOT
Title:	Assistant State Engineer, Maintenance Section
Date:	7/7/93 Telephone Number: (602) 255-7410
Topic:	Robotics and Automation in Construction
Interviewer:	Richard M. Gallegos

Discussion:

Flagging for traffic control: Almost all ways manually done except for long construction periods which they use permanent signal lights.

Culvert clean-out and inspection: Clean-out by either a high pressure hose or a vacuum. Inspection is eyeballed with no video equipment.

Drilled shaft inspection: They mainly done caisson inspection. Refer to Dick Berusch; Structure Engineer, Bridge Maintenance Division; (602) 255-7481; If it is a dry hole then it is a visual inspection. They also can use a nuclear density device that emits gamma rays. Olsen Engineering Incorporated, consultant, has used Cross hole sonic logging. High frequency sound is emitted form 2 inch diameter tubes placed at different depths for many different tests.

Placement of traffic cones: Manually done but with a special truck. The back seat is lowered so that the person sitting in it has an easier time with the cones.

Non-destructive testing of roadway density: George Way; Pavement Services Engineer; (602) 255-8085; Done manually by nuclear gages. He mentioned a Sonic device that Arizona is not using because it is to inaccurate.

Underwater structure inspection - scour and corrosion: Not a problem in the state.

Illumination and Traffic light replacement: Manually done by a crew.

Telephone Questionnaire

Person: Dean Testa State: Kansas DOT
Title: Chief of Construction and Maintenance
Date: 7/8/93 Telephone Number: (913) 296-3576
Topic: Robotics and Automation in Construction
Interviewer: Richard M. Gallegos

Discussion:

Flagging for traffic control: Manually done by stop and slow paddles.

Culvert clean-out and inspection: Inspection is done manually with aid from video equipment. For some long, thin sanitary sewers video equipment is used. For cleaning high pressure water is used. If it is really bad they use a Rotor Semiboar.

Drilled shaft inspection: Done by lowering a man down in cage. Mirrors are sometimes used but video is never used.

Placement of traffic cones: Manually done from the back of a truck. Contractors have used the Cone wheel.

Non-destructive testing of roadway density: Manual by the use of nuclear gages.

Underwater structure inspection - scour and corrosion: Divers are used with no video equipment.

Illumination and Traffic light replacement: Lights are replaced manually by the individual cities.

Telephone Questionnaire

Person:	Jim Jackson State: Missouri Highway and Transportation Department
Title:	Division Engineer, Maintenance and Traffic
Date:	7/8/93 Telephone Number: (314) 751-2785
Topic:	Robotics and Automation in Construction
Interviewer:	Richard M. Gallegos

Discussion:

Flagging for traffic control: Manually done with regular stop and slow paddles in accordance with MUTCD. Plan to try out the SHRP lighted paddles.

Culvert clean-out and inspection: Clean with a shovel or pull a plywood sled through, or they use a high pressure hose with a backward thrust nozzle.

Drilled shaft inspection: Not done very often, but men have been lowered down to inspect.

Placement of traffic cones: Manual.

Non-destructive testing of roadway density: Done manually by nuclear gages during construction.

Underwater structure inspection - scour and corrosion: Divers are field bridge inspectors with no video equipment.

Illumination and Traffic light replacement: Manually done

Telephone Questionnaire

Person:	Clayton Sullivan	State:	Idaho Transportation Department
Title:	Maintenance Supervisor		
Date:	7/7/93	Telephone Number:	(208) 334-8405
Topic:	Robotics and Automation in Construction		
Interviewer:	Richard M. Gallegos		

Discussion:

Flagging for traffic control: Manually done with stop and slow paddles. The men communicate with radios. A portable traffic signal may be used but this is not very often.

Culvert clean-out and inspection: Manually done by a high pressure hose.

Drilled shaft inspection: Not done.

Placement of traffic cones: Manually from the back of a pick up.

Non-destructive testing of roadway density: Manually done spot checks with nuclear gages.

Underwater structure inspection - scour and corrosion: Divers are used with video and 35 mm cameras.

Illumination and Traffic light replacement: Manually done, and he sees no other way.

Telephone Questionnaire

Person:	Carl Cobble State: Tennessee DOT
Title:	Civil Engineer Manager II, Field Maintenance Office
Date:	7/8/93 Telephone Number: (615) 741-2027
Topic:	Robotics and Automation in Construction
Interviewer:	Richard M. Gallegos

Discussion:

Flagging for traffic control: Use paddle boards with high intensity sheeting. Paddles are either stop or slow, shaped as an octagon.

Culvert clean-out and inspection: Inspection is manually done. Contractors are used and they sometimes use video equipment. Box culverts are cleaned by low excavator mining machine. Pipe culverts are cleaned by a sewer cleaner - jet action water and vacuum system (VACTOR).

Drilled shaft inspection: Mark Harland; Structural Engineer;(615) 741-3351; Not really done in state. He has seen men lowered down to inspect, when forced to.

Placement of traffic cones: Manually done by men from a truck. They do use an arrow board on a shadow car when necessary.

Non-destructive testing of roadway density: Done manually by nuclear gages.

Underwater structure inspection - scour and corrosion: Done by the bridge repair division. They use divers. They once did work with the Tennessee Valley Authority which had a remote control unit. (Dr. Boles should receive more information about submersible by 7/16).

Illumination and Traffic light replacement: None is done by the state, it is a local agencies responsibility.

Telephone Questionnaire

Person: Boyd Fronk State: Utah DOT
Title: Supervisor Maintenance Division
Date: 7/13/93 Telephone Number: (801) 975-4952
Topic: Robotics and Automation in Construction
Interviewer: Richard M. Gallegos

Discussion:

Flagging for traffic control: Use only contractors, they provide their own devices and flaggers.

Culvert clean-out and inspection: Inspect by eye ball. Clean with high pressure water and vacuum (VACTOR Jet Rodder).

Drilled shaft inspection: none done in state.

Placement of traffic cones: manually done with trucks and men.

Non-destructive testing of roadway density: Done manually by nuclear gages (TROXLER).

Underwater structure inspection - scour and corrosion: Use divers, with video equipment and a fish finder type radar from the surface.

Illumination and Traffic light replacement: Traffic signals are manually done. Illumination is done by contractors.

Telephone Questionnaire

Person: Gerald D. Dobie State: Michigan DOT
Title: Engineer of Construction
Date: 7/7/93 Telephone Number: (517) 373-2300
Topic: Robotics and Automation in Construction
Interviewer: Richard M. Gallegos

Discussion:

Flagging for traffic control: Manually done. The men use stop and slow paddles with radio communication between them.

Culvert clean-out and inspection: Clean-out when full they use manual excavation. If the culvert is partially full then they would flush it with a water hose. Inspection is done by manually looking into both ends. The inspection of sewers uses video equipment.

Drilled shaft inspection: Looked into from the top with a flashlight. Contractors lower men down in a "coffin" to inspect and clean out.

Placement of traffic cones: All manual, men on trucks.

Non-destructive testing of roadway density: Done manually by nuclear gages (TROXLER).

Underwater structure inspection - scour and corrosion: Use divers with some video equipment.

Illumination and Traffic light replacement: Manually done by maintenance contractors.

Telephone Questionnaire

Person:	Larry Seabrook	State: Georgia DOT
Title:	State Maintenance Engineer	
Date:	7/7/93	Telephone Number: (404) 656-5314
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Manually done. No plans to research on automation is planned in this area.

Culvert clean-out and inspection: They use a high pressure hose to clean-out. Inspection is manually visual with larger culverts. Not very often they rent a camera that follows the water hose through.

Drilled shaft inspection: Not normally done. Have lowered a man down before.

Placement of traffic cones: Manually done by men on a truck. No plans to use the Cone wheel since Larry is convinced it would not work.

Non-destructive testing of roadway density: They use sonic testing for pavement and columns.

Underwater structure inspection - scour and corrosion: Use divers with no video equipment.

Illumination and Traffic light replacement: All manual, men unscrewing light bulb.

Telephone Questionnaire

Person:	Gary L. Hoffman State: Pennsylvania DOT
Title:	Director, Bureau of Maintenance and Operations
Date:	7/8/93 Telephone Number: (717) 787-6899
Topic:	Robotics and Automation in Construction
Interviewer:	Richard M. Gallegos

Discussion:

Flagging for traffic control: Primarily manual. If long term construction then they will use traffic signals.

Culvert clean-out and inspection: Clean-out done by high pressure water or they will shove pipes into to free debris. Inspection is eyeballed. Video is used for long drainage systems.

Drilled shaft inspection: Done by contractors.

Placement of traffic cones: Manually done now. They have purchased the Cone Wheel and plan to implement it soon.

Non-destructive testing of roadway density: Done manually by nuclear gages, which also test for moisture content.

Underwater structure inspection - scour and corrosion: Done by contractors. Researching into sonic, seismic, and ground penetrating radar.

Illumination and Traffic light replacement: Manually done by a telescoping bucket.

Telephone Questionnaire

Person:	William S. Strizich	State: Montana DOT
Title:	Maintenance and Equipment, Bureau Chief	
Date:	7/12/93	Telephone Number: (406) 444-6158
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Manually done by 18 inch stop and slow paddles.

Culvert clean-out and inspection: Inspect with no video, just eyeballed. Contractors do use video for the inspection of storm sewers. Clean-out with a high pressure hose.

Drilled shaft inspection: No inspection done on drilled shafts.

Placement of traffic cones: Manually done with men on a truck. Did consider the Cone wheel but not enough traffic to use on.

Non-destructive testing of roadway density: Done manually by nuclear gages during construction. Also use the Road Rater, but this is more of a strength test.

Underwater structure inspection - scour and corrosion: Contracted out.

Illumination and Traffic light replacement: Manually done by contractors.

Telephone Questionnaire

Person:	David Golden	State: Oklahoma DOT
Title:	Division Manager - Maintenance	
Date:	7/13/93	Telephone Number: (405) 521-2557
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Mainly with men with paddles, but use message boards and dummy flagmen sometimes.

Culvert clean-out and inspection: Clean-out done only when something goes wrong, but he would not say what exactly is done. Inspection is eyeballed.

Drilled shaft inspection: Use specialized contractors.

Placement of traffic cones: Manually done and experimenting with the Cone Wheel.

Non-destructive testing of roadway density: Done manually by nuclear gages. They experimented with everything else and found this method to be the best.

Underwater structure inspection - scour and corrosion: Handled only by contractors.

Illumination and Traffic light replacement: None done by the state. All done by the cities.

Telephone Questionnaire

Person:	Ken Shultz State: Wyoming DOT
Title:	Maintenance Staff Engineer
Date:	7/14/93 Telephone Number: (307) 777-4459
Topic:	Robotics and Automation in Construction
Interviewer:	Richard M. Gallegos

Discussion:

Flagging for traffic control: Use men with regular paddles. They are looking into the SHRP lighted paddles.

Culvert clean-out and inspection: The clean-out uses high pressure water if needed. Inspection is eyeballed, since there is not much of a problem. No video equipment is used now.

Drilled shaft inspection: Usually not done until after failure.

Placement of traffic cones: Manually done with men and a truck. Looked at the Cone Wheel but there is not a lot of coning done so they would not need a machine.

Non-destructive testing of roadway density: Done manually by nuclear gages.

Underwater structure inspection - scour and corrosion: Bridge Division contract divers.

Illumination and Traffic light replacement: All manual.

Telephone Questionnaire

Person:	John D. Nickelson	State: Rhode Island DOT
Title:	Chief Civil Engineer	
Date:	7/15/93	Telephone Number: (401) 277-2378
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Manually done with flags not paddles because the DOT does not like.

Culvert clean-out and inspection: Clean-out doe by a Sewer Jet, reverse nozzle thruster. Not much of a problem with box culverts. Inspection is eye-balled with no video equipment.

Drilled shaft inspection: Do not have drilled shafts in state.

Placement of traffic cones: Done manually, but ordered one Cone Wheel to try out.

Non-destructive testing of roadway density: Done manually by nuclear gages during the construction phase. On last project they used a Falling Weight Deflectometer.

Underwater structure inspection - scour and corrosion: They use divers with still pictures. The cameras are carried down with them.

Illumination and Traffic light replacement: Manual with no automation seen in the future.

Telephone Questionnaire

Person:	Milan D. Lawson	State:	Vermont Agency of Transportation
Title:	Maintenance Engineer		
Date:	7/14/93	Telephone Number:	(802) 828-2587
Topic:	Robotics and Automation in Construction		
Interviewer:	Richard M. Gallegos		

Discussion:

Flagging for traffic control: Use regular stop and slow paddles. Considering the SHRP strobe paddles.

Culvert clean-out and inspection: Cleaned by either a shovel and a wheel barrel or a high pressure hose when greater than 50 percent clogged. Inspection is visual with no electronic equipment used. Showed an interest in using video, but they do not use.

Drilled shaft inspection: by either concrete piling or sand volume calculations.

Placement of traffic cones: Manual with truck and men. Interested in the Cone Wheel for safety reasons, but they do not have one due to low traffic counts.

Non-destructive testing of roadway density: Done manually by nuclear gages. If inspection of concrete then they take samples.

Underwater structure inspection - scour and corrosion: Contract divers. The state does not do at all.

Illumination and Traffic light replacement: Manually done.

Telephone Questionnaire

Person:	Jim Riggs	State: West Virginia DOT
Title:	Regional Engineer	
Date:	7/15/93	Telephone Number: (304) 558-2901
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Use paddles with reflective tape. They do not light up.

Culvert clean-out and inspection: Clean-out with high pressure water. inspection is eye-balled with videos.

Drilled shaft inspection: Not done.

Placement of traffic cones: Manually done or use contractors. He has seen contractors use the Cone Wheel.

Non-destructive testing of roadway density: Done manually by nuclear gages.

Underwater structure inspection - scour and corrosion: Structures division uses divers with no video equipment. They also contract the jobs.

Illumination and Traffic light replacement: All manually by state crew.

Telephone Questionnaire

Person:	Bill Crace	State: Kentucky DOT
Title:	Director, Division of Maintenance	
Date:	7/8/93	Telephone Number: (502) 564-4556
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Manually done by regular stop and slow paddles. They do have some paddles that light up. Contractors use the SHRP paddles.

Culvert clean-out and inspection: Clean-out, when done by the state they use a shovel and excavation equipment. When contractors clean they use high pressure water. Inspection is eye-balled with no video equipment.

Drilled shaft inspection: Daryl Greer (502) 564-2374; Transportation Engineer II; If the hole is dry then they will lower a man. If the hole is shallow enough they will look at it from the top.

Placement of traffic cones: Manually done by men in a pick up. No mechanical Equipment used.

Non-destructive testing of roadway density: Jim Burchett; Construction Engineer; They use the Road Rater and Falling Weight Deflectometer. On bridges they use electricity.

Underwater structure inspection - scour and corrosion: Done by bridge division with poles (feel around).Contract the divers.

Illumination and Traffic light replacement: John Renfro; Electrical Engineer; All manual using bucket trucks.

Telephone Questionnaire

Person:	Keith C. Swearingen	State: Ohio DOT
Title:	Engineer, Bureau of Maintenance	
Date:	7/15/93	Telephone Number: (614) 466-3264
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Manual with regular stop and slow paddles. Occasionally they will use advanced warning signs.

Culvert clean-out and inspection: Clean with high pressure water. Inspect by visual, no video.

Drilled shaft inspection: Rick Ingle;(614) 466-3893; Assistant Engineer of Bridges; Look down with a flashlight. Also use a tape measure, plumb line and level. They also watch the cuttings as they come out.

Placement of traffic cones: Mostly manual. They do have one Cone Wheel.

Non-destructive testing of roadway density: Done manually by nuclear gages.

Underwater structure inspection - scour and corrosion: John Wackerly; Assistant Structural and Inspection Engineer; Hire diving firms.

Illumination and Traffic light replacement: Manually done by a crew with no automation or machines.

Telephone Questionnaire

Person:	Daniel Wattle	State: Nebraska Dept. of Roads
Title:	Signing and Marking Engineer	
Date:	7/9/93 Telephone Number: (602) 255-8085	
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Manual with regular paddles. The lighted paddles are too expensive ($400, SHRP)

Culvert clean-out and inspection: Rolly Heedum; Highway Maintenance Manager;(402) 479-4542; Clean with either high pressure water or pull something through. Inspection is done visually with no video equipment.

Drilled shaft inspection: Mark Traiynowitz; Geotechnical Engineer;(402) 479-4701; Visual by a mirror and plumb line. They also inspect the cuttings.

Placement of traffic cones: All manual. They have no Cone Wheel.

Non-destructive testing of roadway density: Bob Wedner; Materials Engineer; 479-4707; Done manually by nuclear gages. Also use the Falling Weight Deflectometer.

Underwater structure inspection - scour and corrosion: Osvald Bomanis; Bridge Division Engineer; Either by in house divers with no video equipment, or consultants, contractors.

Illumination and Traffic light replacement: All manual.

Telephone Questionnaire

Person:	Bill Darby State: Nevada DOT
Title:	Assistant Engineer, Maintenance Division
Date:	720/93 Telephone Number: (702) 687-5615
Topic:	Robotics and Automation in Construction
Interviewer:	Richard M. Gallegos

Discussion:

Flagging for traffic control: Using regular stop and slow paddles. Experimenting with the lighted ones.

Culvert clean-out and inspection: Clean with high pressure water or a shovel. Inspection is visual with no video equipment.

Drilled shaft inspection: Dave Cochran;(702) 687-5520; Highway Engineer IV, Management Specialist; If the hole is wet then they probe the bottom. When dry they use a plumb line. They do not use any type of video equipment for this purpose.

Placement of traffic cones: Manually done. They have one Cone Wheel in Las Vegas and it works great. They are thinking about purchasing more.

Non-destructive testing of roadway density: Done manually by nuclear gages.

Underwater structure inspection - scour and corrosion: Floyd Macusy;(702)687-5525; Chief, Bridge Division; A diver may be used but usually have shallow, clear water.

Illumination and Traffic light replacement: Illuminiers are done by state crews, manually. Traffic lights are taken care of by the individual cities.

Telephone Questionnaire

Person:	Wayne Cobine	State: Oregon DOT
Title:	Operations Manager, Construction, Maintenance, and Materials	
Date:	7/20/93	Telephone Number: (503) 378-6528
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Manually with stop and slow paddles. May use signs to warn about flagmen.

Culvert clean-out and inspection: Clean by a shovel or back hoe, or if it is fully plugged then they use high pressure water(backward nozzle). Inspect by visual on existing structures. Newly built structures they may use video equipment.

Drilled shaft inspection: Contract work.

Placement of traffic cones: All manual.

Non-destructive testing of roadway density: Done manually by nuclear gages during construction.

Underwater structure inspection - scour and corrosion: Use state divers with some video equipment.

Illumination and Traffic light replacement: Illuminiers are mostly contracted, while the state may do some. Traffic light replacement is done by the state, all manual, no automation.

Telephone Questionnaire

Person:	John Howard	State: Minnesota DOT
Title:	Maintenance, Standards, and Operations Engineer	
Date:	7/21/93	Telephone Number: (612) 297-3593
Topic:	Robotics and Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Mostly manual. They do use arrow boards, signs, and regular paddles. They are experimenting with one less person in the wok zone by using mechanical-portable signs, warning zones, off duty officer, and portable speed bumps. For more information call John Jackels (612) 296-2721.

Culvert clean-out and inspection: Clean with high pressure steam, seasonal problems (freezing). Inspect visually with no video equipment.

Drilled shaft inspection: Very infrequent, use consultants.

Placement of traffic cones: Manual. May have a Cone Wheel. Talk to Greg Felt 725-2354 for more information.

Non-destructive testing of roadway density: Done manually by nuclear gages during construction.

Underwater structure inspection - scour and corrosion: Mostly by contractors and occasionally may send own divers.

Illumination and Traffic light replacement: Illuminiers are replaced by the utility company while the traffic lights are replaced manually by a state crew.

Telephone Questionnaire

Person:	Allen Wells	State: California DOT
Title:	Office Chief, Division of Maintenance	
Date:	8/9/93 Telephone Number: (916) 654-5849	
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Mainly use flags and hand signals. They also use regular stop and slow paddles.

Culvert clean-out and inspection: Clean-out is manual with the use of a Vactor trucks. Inspection is mainly eye-balled with some video equipment used.

Drilled shaft inspection: They do inspect pumping stations but do not inspect drilled shafts.

Placement of traffic cones: Manually placed by men on a Cone truck. This truck has a lowered seat in the rear for easier access. He does not see good results coming from the Cone wheel.

Non-destructive testing of roadway density: Jim MacFarlane, Materials and Research Engineer, Assistant New Technology Research (916) 227-7000, Done manually by nuclear gages.

Underwater structure inspection - scour and corrosion: Carl Harris, Office of Maintenance (916) 227-8229, they use in-house divers and contract out divers. Carl said that they also use still cameras with plastic shields holding clear water. Hydraulics division uses fish finders.

Illumination and Traffic light replacement: Review monthly at night by a crew that manually replaces the light bulbs.

Telephone Questionnaire

Person:	Jesse Gilstrap	State: North Carolina DOT
Title:	Traffic Control Design Engineer	
Date:	8/9/93 Telephone Number: (919) 250-4159	
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Use regular paddles and flags. They use warning signs, message boards, and arrow boards. Jim Kellenberger, Traffic Control Project Engineer (919) 250-4159, said that this state is trying to replace flaggers with portable traffic signs even in short term construction.

Culvert clean-out and inspection: Don Idol, Assistant Bridge Inspection Engineer (919) 733-4362, clean-out is done only when there is a problem. Sometimes they let the rivers clean out the culverts by themselves during a storm. Otherwise they use backhoes and shovels. Inspection is eye-balled when the culvert is greater than 20 feet high. They do not inspect culverts less than 20 feet high.

Drilled shaft inspection: Nari Abar, Soils Engineer (919) 250-4128, they do lower a man down to inspect the bottom. No video equipment is used even though most drilled shafts are dry. If it is wet they pump the water out.

Placement of traffic cones: Manually done with men on a pick-up truck with impact attenuators. They like to use alot of plastic drums. Jim K. says that maintenance division uses a Cone wheel, but only on multilane highways. You cannot use a Cone wheel effectively on a two lane, two way highway.

Non-destructive testing of roadway density: Shane Wu, Assistant State Pavement Management Engineer (919) 250-4094, done manually by nuclear gages. They use destructive testing (cores) for checking.

Underwater structure inspection - scour and corrosion: Glenn Williams, Bridge Inspection Supervisor II (919) 733-4362, they use 12 in-house divers. Armed with boats, vans, and a surface air compressor. The divers use video and still shots. Pathometer gives profile readings.

Illumination and Traffic light replacement: Milton Dean, Signals Maintenance Engineer (919) 733-3915, each state division takes care of manually by crews.

Telephone Questionnaire

Person:	Norm Humphrey	State: South Dakota DOT
Title:	State Maintenance Engineer	
Date:	8/17/93	Telephone Number: (605) 773-3571
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Exclusively done with regular stop and slow paddles. Some flags are used.

Culvert clean-out and inspection: Inspection is eye-balled with no video equipment used. The ends are cleaned out with a loader, shovels, or forks depending on the job. During the winter they use a steamer to aid in cleaning.

Drilled shaft inspection: Men used to go down. Mike Durik, State Construction Engineer (605) 773-3571, they are not very deep (less than 20 feet) so the are looked at from the surface. Not many are done in this area, and no men are now lowered.

Placement of traffic cones: Manually placed but use barrels mainly.

Non-destructive testing of roadway density: Gill Hadman, Pavement Design Engineer (605) 773-3401, done manually by nuclear gages, which are based on cores. They are going to use a Falling Weight Deflectometer later this year.

Underwater structure inspection - scour and corrosion: Use consultants only with no in-house divers.

Illumination and Traffic light replacement: Illuminiers are contracted out or done by the utility company. Traffic lights are contracted out or done by the individual cities.

Telephone Questionnaire

Person:	Gill Gaustreau	State:	Louisiana DOT & Development
Title:	Bridge Maintenance Structural Engineer		
Date:	8/17/93	Telephone Number:	(504) 379-1551
Topic:	Automation in Construction		
Interviewer:	Richard M. Gallegos		

Discussion:

Flagging for traffic control: They use regular paddles and flags with communication between flaggers.

Culvert clean-out and inspection: Clean-out is not done alot, but when done they use shovels or a small dozer. High pressure water is used only on bridges and underwater structures. Inspection is eye-balled but divers are used when a culvert is underwater.

Drilled shaft inspection: Not done in state. Only one bridge had this in the state.

Placement of traffic cones: In maintenance it is done manually and they have no cone wheel. In construction it is contracted out. Long term construction they use portable barriers and barrels.

Non-destructive testing of roadway density: Bill Hickey, Road Design Engineer (504) 379-1303, done manually by nuclear gages. The Troxler is mainly used. Sometimes they use the sandcone on small projects.

Underwater structure inspection - scour and corrosion: Wayne Amen, Bridge Design Engineer (504) 379-1332, they use in-house divers and consultants.

Illumination and Traffic light replacement: Francis Becnel, Traffic Services Engineer (504) 935-0101, 9 districts have their own crews to manually do with no automation.

Telephone Questionnaire

Person:	John Bjorke	State: North Dakota DOT
Title:	State Maintenance Engineer	
Date:	8/4/93	Telephone Number: (701) 224-4425
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Using flags and regular paddles, or they are contracting out. He is not pushing the SHRP paddles.

Culvert clean-out and inspection: Clean-out is manually done with a front end loader and high pressure water. Inspection is eye-balled.

Drilled shaft inspection: Not done in this state.

Placement of traffic cones: Manually done.

Non-destructive testing of roadway density: Just cores, no nuclear gages.

Underwater structure inspection - scour and corrosion: All contracted out.

Illumination and Traffic light replacement: Traffic signals are manually replaced and contracted out. Illuminiers are all contracted out.

Telephone Questionnaire

Person:	John Pezik	State: New Jersey State Department of Transportation
Title:	Project Engineer in Maintenance	
Date:	8/18/93	Telephone Number: (609) 530-3858
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Mostly use regular paddles and communication between flaggers. They use flags on state roads. They have purchased SHRP paddles.

Culvert clean-out and inspection: Clean-out on an as needed bases. They clean debris out with a shovel, excavator, or a crane. Inspection is eye-balled.

Drilled shaft inspection: Robert Scancella, Project Engineer, Bureau of Maintenance (609) 292-4908, have not done in the past 10 years of construction.

Placement of traffic cones: Manually placed and picked up. Follow MUTCD by using an arrow board with attenuator. They also use barrels.

Non-destructive testing of roadway density: Robert S., done manually by nuclear gages in the back scatter mode.

Underwater structure inspection - scour and corrosion: Robert S., Mostly consultants are used since this is not done very often. Sonar was used once.

Illumination and Traffic light replacement: Larry Sroka, Electrical Engineer (609) 530-3725, either manually done by crews or contracted out.

Telephone Questionnaire

Person:	Dean Bennett	State: New Hampshire DOT
Title:	Chief, Bridge Inspection	
Date:	8/4/93	Telephone Number: (603) 271-3667
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Jim County, Pavement Monitoring, Team Leader (603) 271-2291, using regular stop and slow paddles, according to MUTCD. Construction has message boards.

Culvert clean-out and inspection: Clean-out is done manually and uses high pressure water. Inspection is Eye-balled and still pictures are used.

Drilled shaft inspection: Not done in this state.

Placement of traffic cones: Jim C., all manual with no automation.

Non-destructive testing of roadway density: Allan Perkins, Chief of Material and Technology (603) 271-3151, mainly done by coring and some nuclear gages.

Underwater structure inspection - scour and corrosion: Use consultants and contractors only. Contractors do use sonar. The state may also probe.

Illumination and Traffic light replacement: Perley Sherette, Traffic Signal Technician (603) 271-2291, traffic lights are handled by state maintenance crews. Illuminiers are all handled by the power company.

Telephone Questionnaire

Person:	Bob Mayprey	State: Mississippi DOT
Title:	State Traffic Engineer	
Date:	8/17/93 Telephone Number: (601) 944-9333	
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: They use flags and regular paddles during construction. Long term construction requires the use of temporary traffic signals.

Culvert clean-out and inspection: Gary Hillman, Assistant State Maintenance Engineer (601) 359-1145, clean-out is manual by a front end loader or a high pressure hose. Inspection is eye-balled although they used video equipment once 4 or 5 years ago because they knew of a separation.

Drilled shaft inspection: John Taylor, Rating and Inspection Engineer (601) 359-1181, not really done in this state, mainly use piles.

Placement of traffic cones: Manually from the back of a pick-up.

Non-destructive testing of roadway density: Bob Denson, Pavement Engineer, Research Department (601) 359-1174, not really done in state. Use sand cone now along with a Dynaflect (FWD), and some nuclear gages.

Underwater structure inspection - scour and corrosion: John T., they contract out every 5 years. They have no in-house divers.

Illumination and Traffic light replacement: Crews do manually.

Telephone Questionnaire

Person:	Tim Crouch	State: Iowa DOT
Title:	Traffic Control Engineer	
Date:	8/5/93	Telephone Number: (515) 239-1519
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Use regular stop and slow paddles. They have ordered some SHRP paddles.

Culvert clean-out and inspection: Dwight Rorholm, Maintenance Operations Engineer (515) 239-1589, clean-out is not done very much. They do use high pressure water and small bobcats. Inspection is mainly eye-balled, but they also use a camcorder pulled through on a trolley. But, this is not consistent throughout the state.

Drilled shaft inspection: Jim Rost, Geotech (515) 239-1352, if the drilled shaft is wet then no video equipment is used, just a plumb bob measurement. If the shaft is dry a man may be lowered or video equipment used.

Placement of traffic cones: Tim C., all manual.

Non-destructive testing of roadway density: Jerry Bergren, Assistant State Materials Engineer (515) 239-1600, done manually by cores, mix gages, and some nuclear gages. They also contract out.

Underwater structure inspection - scour and corrosion: Tim Dunley, Assistant Head Engineer, Bridge Maintenance Division (515) 239-1206, they hire divers once the water reaches a certain limit on the pier. These divers use depth finders to detect scour.

Illumination and Traffic light replacement: Dwight Steven, State Traffic Engineer (515) 239-1513, traffic lights are replaced by each city. Illuminiers are done by maintenance crews or by cities.

Telephone Questionnaire

Person:	Jack Brown	State: Florida DOT
Title:	State Traffic Operations Engineer	
Date:	6/30/93	Telephone Number: (904) 488-4284
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Use flags and regular paddles. Going to research the SHRP paddles.

Culvert clean-out and inspection: Marshall Stivers, State Maintenance Engineer (904) 488-8814, clean-out is manual with shovels. Inspection is eye-balled.

Drilled shaft inspection: Peter Lai, Assistant State Geotechnical Engineer (904) 488-6351, they do not lower a man down the shaft since it is too wet. They also check the plumbness and use a slurry under time limits. On major projects they use a Shaft Inspection Device which is a diving bell with a camera. It can scoop the bottom clean and take a sample of the side wall.

Placement of traffic cones: Manually done now.

Non-destructive testing of roadway density: Done manually by nuclear gages.

Underwater structure inspection - scour and corrosion: Use divers and cameras.

Illumination and Traffic light replacement: This is done by others.

Telephone Questionnaire

Person:	Mike Nesbitt	State: Washington DOT
Title:	Traffic Control Engineer	
Date:	8/6/93	Telephone Number: (206) 705-7293
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: No flags are used, just regular paddles. They have planned flagging operations. Recognition of a flagger is easier with a paddle.

Culvert clean-out and inspection: Dave Bauers, Road Maintenance Engineer (206) 705-7862, clean-out is manual, using high pressure water, dynamite, a clam shell that they pull through, and a scraper bucket.

Drilled shaft inspection: Chuck Ruth, Bridge Construction Engineer (206) 705-7821, vertical alignment is checked by the plumbness of the shaft. Small shafts are looked down from the surface. They may contract out and they may lower a man down. Sonic logging was used once and it worked well.

Placement of traffic cones: Manually done but will occasionally contract out. They have tested and rented some cone wheels but they are not used.

Non-destructive testing of roadway density: Dean Lokken, Electrical Engineer (206) 753-2187, done manually by nuclear gages and checked by coring.

Underwater structure inspection - scour and corrosion: Hugh Favero, Senior Bridge Condition Engineer (206) 753-4739, they hire divers that have used sonar devices.

Illumination and Traffic light replacement: Crews take care of manually.

Telephone Questionnaire

Person:	Chuck Loerwald	State: Colorado DOT
Title:	Maintenance Manager Coordinator	
Date:	8/5/93	Telephone Number: (303) 757-9203
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Bruce Benson, Engineer Technician II (303) 757-9272, use regular stop and slow paddles.

Culvert clean-out and inspection: Clean-out is mostly manual with high pressure water. They also use a skid steer loader. Inspection is eye-balled, not a routine basis.

Drilled shaft inspection: None done in this state.

Placement of traffic cones: Bruce B., all manual. No machine used.

Non-destructive testing of roadway density: Charlie MacKeen, Engineer B (303) 757-9249, done manually by nuclear gages.

Underwater structure inspection - scour and corrosion: Walt Mistkowski, Bridge Inspection Engineer (303) 757-9338, if water is greater than 4 feet then contract out to diving firms. This is usually the case.

Illumination and Traffic light replacement: Crews go out and do manually or contracted with the Public Service Company.

Telephone Questionnaire

Person:	Jim Bennett	State: South Carolina
Title:	Civil Engineer III	
Date:	8/10/93	Telephone Number: (803) 737-1459
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Normally use regular paddles. Flags used only in emergencies.

Culvert clean-out and inspection: Huley Shumpert, Assistant State Maintenance Engineer (803) 737-1290, clean-out with Jet Rodder trucks. Inspection is eye-balled, but the local sewer authorities use video equipment on small pipes.

Drilled shaft inspection: Charles L. Matthews, Bridge Engineer, Construction (803) 737-1490, they do send a man down. Video equipment is used but there is a moisture problem. Usually the shafts are short enough that visual inspection from the surface will suffice. They have a specialized camera that is tilted 90 degrees to one side. It did not really work to well.

Placement of traffic cones: Jim B., all manual. They have no cone wheel.

Non-destructive testing of roadway density: Huley S., done manually by nuclear gages.

Underwater structure inspection - scour and corrosion: Lee Floyd, Bridge Inspection Engineer (803) 737-1490, consult with diving firms.

Illumination and Traffic light replacement: Huley S., manually done by a crew on a complaint basis.

Telephone Questionnaire

Person:	Chuck Sterling III	State: Massachusetts
Title:	State Traffic Engineer	
Date:	8/10/93	Telephone Number: (617) 973-7360
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: No flagging is done, they use state troopers due to union issues.

Culvert clean-out and inspection: Tony Petronio, Maintenance Engineer (617) 973-7740, to clean-out a dry culvert they use conventional excavating equipment. If a culvert is underwater then they use dredges. Inspection is eye-balled and video is used only when there is a problem.

Drilled shaft inspection: Paul Mardone, Bridge Inspection Engineer (617) 973-7570, none done in this state. If done then it is probably contracted out.

Placement of traffic cones: Chuck S., manually done.

Non-destructive testing of roadway density: Leo Stevens, Materials and Research Engineer (617) 235-6100, done manually by nuclear gages and coring.

Underwater structure inspection - scour and corrosion: Paul M., use in-house divers or consultants. Use still cameras. Just ordered special cameras to aid in murky waters.

Illumination and Traffic light replacement: Chuck S., all contracted and replaced on an as needed basis.

Telephone Questionnaire

Person:	Woody Woodward State: Virginia DOT
Title:	Assistant Maintenance Division Administrator
Date:	8/4/93 Telephone Number: (804) 786-2847
Topic:	Automation in Construction
Interviewer:	Richard M. Gallegos

Discussion:

Flagging for traffic control: Use regular stop and slow paddles.

Culvert clean-out and inspection: Clean pipes manually and by augurs. Clean box culverts by high pressure water. Inspection is still eye-balled.

Drilled shaft inspection: Not looked in the state.

Placement of traffic cones: Lynwood Butner, State Traffic Engineer (804) 786-2965, manually done now since they tested the cone wheel but they did not like.

Non-destructive testing of roadway density: Richard Steel, Assistant State Materials Engineer (804) 328-3102, done manually by nuclear gages. Cores are taken to check voids. They also use a thin mix gage.

Underwater structure inspection - scour and corrosion: Use divers.

Illumination and Traffic light replacement: Manually done by crews or contracted out. They use a preventive maintenance system.

Telephone Questionnaire

Person:	Bill Muholland	State: Arkansas
Title:	State Maintenance Engineer	
Date:	8/5/93 Telephone Number: (501) 569-2251	
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Mostly use flags, tried regular stop and slow paddles, but only use sometimes.

Culvert clean-out and inspection: Clean-out end with hydraulic excavator, dig in culvert with shovels and then flush with high pressure water. Inspection is eye balled periodically.

Drilled shaft inspection: Not used in Arkansas.

Placement of traffic cones: Manually done.

Non-destructive testing of roadway density: Done manually by nuclear gages. Coring sometimes in construction.

Underwater structure inspection - scour and corrosion: Divers and contracted.

Illumination and Traffic light replacement: Both are maintained by cities or town. Tried using power company for overhead signs.

Telephone Questionnaire

Person:	Dave Vieph	State: Wisconsin DOT
Title:	Chief of Programs for Highway Maintenance Office	
Date:	7/14/93	Telephone Number: (608) 266-7594
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Use regular paddles. Thinking about getting the SHRP paddles.

Culvert clean-out and inspection: Clean-out is done by a high pressure steamer. Inspection is eye balled.

Drilled shaft inspection: Bob Anderdofer, Geotech (608) 246-7940, no inspection is done. No men are sent down and there are no machines to do.

Placement of traffic cones: Manually done by men in a pick-up. Contractors may use the cone wheel.

Non-destructive testing of roadway density: Bill Duckert, Manual Pavement Engineer (608) 246-7955, done manually by nuclear gages.

Underwater structure inspection - scour and corrosion: Use contractors or in-house divers. In-house divers must feel around due to the turbidity and no video equipment can be used.

Illumination and Traffic light replacement: All done manually by crews. High mass lighting is collapsible to ease the crews job.

Telephone Questionnaire

Person:	Dennis Ho	State: Delaware DOT
Title:	Central District Engineer	
Date:	8/4/93	Telephone Number: (302) 739-4219
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Ray Pusey, Division of Highway, Director (302) 739-4361, Use regular paddles and no flags.

Culvert clean-out and inspection: Cleaned with a hydraulic excavator, shovels, and clam shell. On concrete pipe they use a pipe flusher. Inspection is still eye-balled and is on an as needs basis.

Drilled shaft inspection: Not inspected because they have a clay and sandy soil.

Placement of traffic cones: All manually done, mostly subcontractors do.

Non-destructive testing of roadway density: Done manually by nuclear gages.

Underwater structure inspection - scour and corrosion: All contracted out.

Illumination and Traffic light replacement: All manually done by a crew on a schedule maintenance basis or on demand.

Telephone Questionnaire

Person:	Gary Maines	State: Maine DOT
Title:	Assistant Highway Maintenance Engineer	
Date:	7/22/93	Telephone Number: (207) 287-2661
Topic:	Automation in Construction	
Interviewer:	Richard M. Gallegos	

Discussion:

Flagging for traffic control: Regular paddles are used mostly. They have ordered three SHRP paddles. Maintenance uses paddles always.

Culvert clean-out and inspection: They clean manually with high pressure water and during the winter they use old steamers and boilers. Inspection is eye-balled now but there is a company that has video equipment for culverts less than 36 inches.

Drilled shaft inspection: Driven pilings used only.

Placement of traffic cones: Manually done.

Non-destructive testing of roadway density: Use the Rotor Rater. They also have an ARAN vehicle which gives a continuous photograph of the pavement.

Underwater structure inspection - scour and corrosion: Gary Hoer, Bridge Maintenance Engineer (207) 287-2729, they use 13 volunteer in-house inspection divers. No video equipment or automation is used and the divers must sometimes feel around. They sometimes contract divers to do the job.

Illumination and Traffic light replacement: Ed King, Traffic Engineer (207) 287-3775, Traffic lights are replaced manually by a bucket truck. Illuminiers are also replaced manually and have a drill assembly that lowers them down.

Telephone Questionnaire

Person:	John Scally	State: Maryland DOT	
Title:	Assistant to the Deputy Chief Engineer of Maintenance		
Date:	7/21/93	Telephone Number: (410) 859-7363	
Topic:	Automation in Construction		
Interviewer:	Richard M. Gallegos		

Discussion:

Flagging for traffic control: Use regular paddles only.

Culvert clean-out and inspection: Clean manually and with high pressure water. Inspection is eye-balled with no automation.

Drilled shaft inspection: Joe Miller, Director and Chief of Bridge Repair (410) 333-1175, not done in state.

Placement of traffic cones: Manually done or contracted. Contractors may have the cone wheel.

Non-destructive testing of roadway density: Ray Dotterweich, Assistant Deputy Chief Engineer of Materials and Research (410) 321-3541, done by nuclear gages.

Underwater structure inspection - scour and corrosion: Paul Perkins, Assistant Chief Engineer (410) 333-1169, they have in-house divers that probe below the mud line. If there is clear water it is visual inspection, if the water is dirty they feel around.

Illumination and Traffic light replacement: Done by state crews manually.

APPENDIX G

MANUFACTURERS CONTACTED

Ferranti O.R.E. Inc.
Jimmy Reynolds-(713) 879-7277
Bridge Scour, mailed 8/24

Hydro Services Inc.
Mike Grasey-(713) 499-8611
Rotomole, mailed 8/4

Addco
Ron Lindenfelser-(612) 224-8800
Cone Wheel, mailed 7/12

SHRP
(202) 334-3774
Product catalog, mailed 7/21

Hydro Products
Pat Raetzman-(619) 792-2100
Submersible, mailed 7/12

PLS International
(216) 252-7770
Eric 360, mailed 7/12

Lenox Instruments
(215) 322-9990
Borescope, mailed 7/12

Fibertron
(713) 861-3062
Fiberscopes, mailed 7/12

Troxler
(817) 275-0571
Nuclear Density Gage, mailed 8/5

American Inland Divers
Gordon Barksdale-(713) 462-9080
Sonar, mailed 8/5

Mesotech
Roger Rouleau-800-767-4331
Side Scan Sonar

Benthos Inc.
Eric Gifford-(508) 563-1000
Remote Viewing Equipment, mailed 7/20

Visual Inspection Technologies Inc.
(201) 927-0033
Articulating Probe, mailed 7/13

Roadware Corp.
(519) 442-2264
ARAN Vehicle, mailed 8/4

Foundation Mechanics Inc.
Bill Johnson-(310) 322-1920
FWD, mailed 7/13

Companies talked to but did not have information on products:

T.J. Hall Inc.
Ted Hall-(409) 756-8818
Rotomole

Smith and Company
Ted Hall-(409) 756-6960
Rotomole

Hydro Services Inc.
Paul Franklin-(409) 233-2601
Rotomole

Deep Sea Systems International Inc.
Chris Nicholson-(508) 540-6732
Submersible

Gas Research Institute
Dave Hill-(312) 399-8100
Drilled shaft inspection, mailed 7/12

Southwest Research Institute
(210) 522-5105
Rotating camera and mirror

Carylon Corp.
(312) 666-7700
Micro-TV

Kaselaan and D'Angelo Associates, Inc.
(609) 547-6500
Side Scan Sonar