AUTOMATION AND ROBOTICS IN HIGHWAY DESIGN, CONSTRUCTION, AND MAINTENANCE

AUTOMATION AND ROBOTICS
Past, Present, and Future

CHRIS HENDRICKSON

Although highway construction and maintenance have become highly mechanized, only specialized applications of automation and robotics have been implemented. The underlying technology for automated fieldwork, however, continues to improve and to become less expensive. Computer hardware alone has been increasing in capability at a rate of 30 percent per year, and distributed computing is a key technology for field automation. New sensors and control systems are also appearing. This technological revolution will lead to significant opportunities for roadway construction and maintenance.

This special issue of TR News *focuses on automation and robotics in design, construction, and maintenance. Presented in the following articles are some basic definitions of robotics and automation, answers to often-asked questions, and a review of the current state and prospects of new automated systems.*

Appreciation is expressed to TRB staff members Frederick D. Hejl, Engineer of Materials and Construction, and G. P. Jayaprakash, Engineer of Soils, Geology, and Foundations, for overseeing the preparation of this issue on automation and robotics.

Chris Hendrickson is Associate Dean and Professor, Department of Civil and Environmental Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania.

What is automated and robotic equipment?

In contrast to the image developed in popular movies, robotic equipment is not necessarily humanoid, with walking legs and mechanical arms. The many degrees-of-freedom arms seen on industrial robots used for welding or paint spraying have only limited roles to play in field construction or maintenance. A more important consideration is the type of control and sensing used.

Construction and maintenance equipment can be divided broadly into four categories of control:

- *Mechanized equipment* is familiar in most field applications for tasks such as grading, excavation, and maintenance.
- *Numerically controlled equipment* is in common use for slipforming and paving applications. NC machines use limited sensors only for tasks such as following a straight line or regulating the flow of materials.
- *Remotely controlled equipment* has physically separate operators that typically must rely on sensor information to operate the equipment effectively.
- *Semiautonomous and autonomous equipment* relies on environmental sensors and computer algorithms to make decisions about equipment operation and movement. For example, semiautonomous grading equipment is driven by a human operator but the blade height and pitch may be controlled automatically. An autonomous dump truck could drive itself to and from loading and dumping areas.

Although there are always exceptions and qualifications, remotely controlled and semiautonomous and autonomous types of equipment are commonly considered automated or robotic equipment.

What can automated and robotic equipment contribute?

Improved safety is the most obvious advantage of automated equipment. Roadway maintenance in active traffic areas is inherently hazardous, even with special barriers, warnings, and protective procedures. Bridge and pier inspection carries the risk of injuries and avoiding a single fatality or major injury could justify the use of new equipment. Health hazards are associated with some roadway construction and maintenance tasks, such as removing lead-based paint, and the use of robots could keep humans out of range of such danger.

The opportunity to take advantage of superhuman capabilities is another benefit offered by automation. Small robots can move through drainpipes for inspection and repair. Sensors can pinpoint reinforcing steel embedded in concrete. Precise control of actions such as crack cleaning could lead to improved quality. With automated machinery, work could continue for long periods without the complication of complaints about night shifts or overtime.

What are possible applications for this equipment?

The ideal application for automated and robotic equipment would (*a*) include high costs to justify new equipment investments; (*b*) have high volume to spread development and investment costs over numerous applications; (*c*) be performed within a hazardous environment; (*d*) involve simple, repetitive tasks; and (*e*) have a stable and predictable environment to avoid the necessity for sophisticated monitoring and control. Few roadway construction and maintenance tasks include all these characteristics, especially a stable and predictable environment, but many have some of these ideal elements. Numerous possible applications are discussed in the following articles.

How do automation and robotics relate to computer-aided design (CAD) and intelligent transportation systems?

Transportation systems have pockets of automation and of computer-based representations. For example, CAD drawings are being prepared for new roadways, but the actual construction is still based on paper printouts from the CAD system. In addition, many trucking firms track their vehicles automatically throughout the country using global positioning systems and other technologies. Toll collection and vehicle identification are also being automated, but these pockets are usually isolated from each other and from nonautomated processes. Some significant benefits are likely to result when these pockets of automation are extended and interconnected. For example, construction progress can be monitored and quality assured with field sensors and real-time information feedback. Accurate electronic models of facilities in place can be used for maintenance automation and for intelligent roadway operations.

What is slowing the introduction of automation and robotic equipment?

Roadway construction and maintenance present some extreme equipment demands. The environment is rugged, large forces are required, equipment longevity is imperative, the underlying tasks are diverse, and stringent cost restrictions are the rule. Most robot implementations to date have been

In contrast to the image developed in popular movies, robotic equipment is not necessarily humanoid, with walking legs and mechanical arms.

conducted in controlled environments such as manufacturing plants, so field applications require some additional development. Even in industrial plants, successful automation has required the redesign and reengineering of manufacturing tasks as well as extensive experimentation and training for personnel. Both technical challenges and organizational barriers to change must therefore be overcome before use of new equipment can become widespread.

Will automation and robotic equipment be introduced in the near future?

In many cases automation has already been introduced and is moving toward more capability and machine control. Examples of existing automation are flow controls for pavers and height controls on grading equipment. Engine maintenance is being automated with extensive computer monitoring and diagnostic aids. Sophisticated guidance and control technology is used in tunneling technology. In addition to this evolutionary improvement, the introduction of new, specialized equipment with robotic characteristics is likely for applications such as bridge inspection or painting. Although complete replacement of construction and maintenance personnel will not take place in the near future, workers will increasingly become equipment managers, responsible for monitoring and managing the work of automated systems.

What are the implications of these changes for the future work force?

As is the case in many sectors of the economy, these technological changes will put a premium on broad-based technical skills for both workers and engineers. Some basic knowledge of electrical circuits and computers will be helpful for field workers. For engineers, interdisciplinary problem-solving skills will be needed, and a civil engineering education should include exposure to electromechanical devices and the professional uses of computer systems. In future years a master of science degree may become the normal requirement for work as a professional engineer.

The efforts of Chris Hendrickson, past Chairman of TRB's Committee on Applications of Emerging Technology, are acknowledged in planning this issue of TR News *focusing on automation and robotics in highway design, construction, and maintenance, in acquiring the articles, and in overseeing the review process.*

—Nancy Ackerman
Editor, *TR News*