RESEARCH PROGRESS INTO AUTOMATED PIPING CONSTRUCTION

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Introduction

In its report, *Construction Technology Needs and Priorities*, the Business Roundtable identified piping as the most inefficient of major construction tasks and one of the three areas having the highest potential for technical advancement. [2] On average, piping work comprises 24% of heavy industrial projects, 16% of power plants, and 12% of light industrial projects. Even moderate technological advances in piping work should deliver sizable returns on investment. The economic results of automation in piping work could be very significant.

Conventional pipe construction practice is complex and grossly inefficient. The several steps of spool fabrication, transport, erection, alignment, connection, inspection, and testing are each plagued with unique problems. Spool fabrication remains a largely manual activity utilizing little sophisticated equipment. Pipe erection is an awkward, often poorly coordinated task. When cranes cannot be used, pipefitters must use manual lifting devices such as chain falls and come-alongs. Pipe alignment requires great skill and is highly dependent on technical information, but on most sites a plumb bob and level are still the standard alignment tools. Alignment of large diameter pipe is a particular problem and necessary tools often must be fabricated on site. Tolerance buildup make pipe alignment difficult and time consuming. Connections represent 25% of the total time for pipe installation. Welding is also very problem prone. Much of the inconvenience and costliness of welding stems from the bulkiness of welding equipment. As stated in the Business Roundtable Report [2], "the application of automatic welding technology to industrial construction may hold some promise for solving a number of the problems."

Research Objective

The prime research objective is the automation of the pipe construction process from fabrication through inspection. The thrust of the study is toward the development and integration of three pipe technologies: pipe bending, pipe manipulation, and welding. Initial research activities are focused on system issues related to the overall automated process, and detailed analyses of pipe manipulation.

The envisioned automated system involves a single human operator of a pipe manipulator with an ability to communicate efficiently with automatic pipe benders and in situ automatic welders. The system is based on a recognition that in the highly unstructured construction environment there is generally an optimum mix between humans and intelligent equipment.

The integration of components is a prime challenge in achieving the objective. The fundamental engineering research issue of integrated data management will involve investigations into evolutionary stages of automation, integration with CAD and project management control systems, piping constructability framework, and needed manipulator enhancements.

Industrial Participation

Research and development personnel from Bechtel National, Inc. participate in research activities by serving in an advisory capacity. In addition, the Engineering Department of E. I. du Pont de Nemours & Company has made available a pipe manipulator developed by the Grove Manufacturing Company. This multi-functional material positioner consists of a gravity-leveled operator's control station, telescoping arm, lift cylinders, and jaw assembly. (see Figure 1 below)

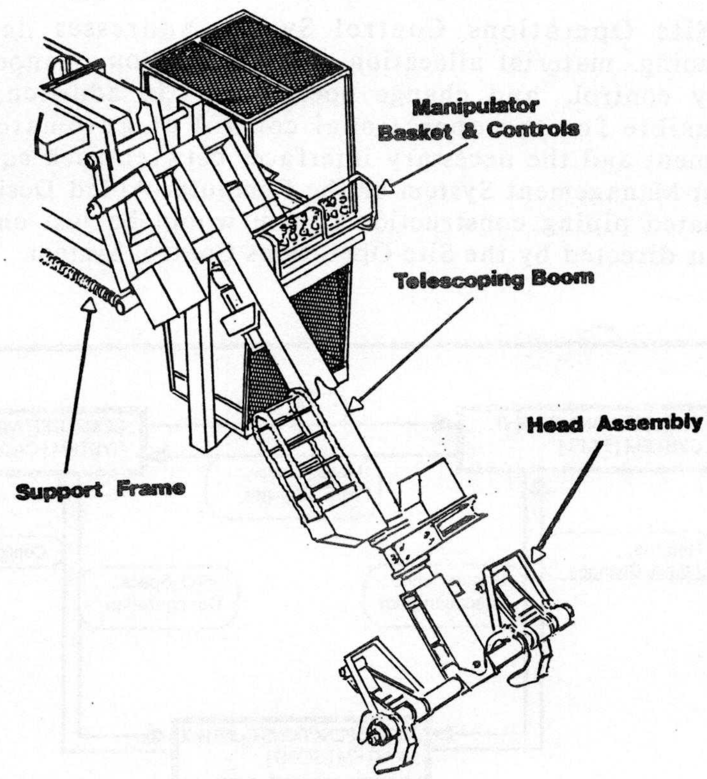

Figure 1: The pipe manipulator and its major components

Information Systems Overview

The Systems Overview depicted in Figure 2 is an attempt at placing the automated piping construction system into perspective relative to automated data systems. Of course data structuring is critical to the development of automated systems, so an early understanding of system interfaces is necessary. The following observations are offered:

1. Three major data management systems are envisioned: the Project Management System, the Computer-Aided Design System, and the radically distinct, yet absolutely necessary for the automated construction environment.

2. The Project Management System may be viewed as the "master system" and encompasses such domains as project scope definition and control, the master schedule, cost engineering, quality assurance, strategic planning, change management, and master documentation.

3. The Computer Aided Design System is used to develop and manage the three-dimensional configuration and element attributes such as specifications. Thus,engineering analysis software is treated as a subsystem. Additional functions include material take-off, interference checking, alignment checking, and as-built documentation.

4. The Site Operations Control System addresses detailed activity sequencing, material allocation and distribution, manpower utilization, quality control, and change operations. In addition, this system is responsible for the operational control of automated construction equipment and the necessary interfaces between such equipment and the Project Management System or the Computer-Aided Design System. The automated piping construction system would be just one of many such systems directed by the Site Operations Control System.

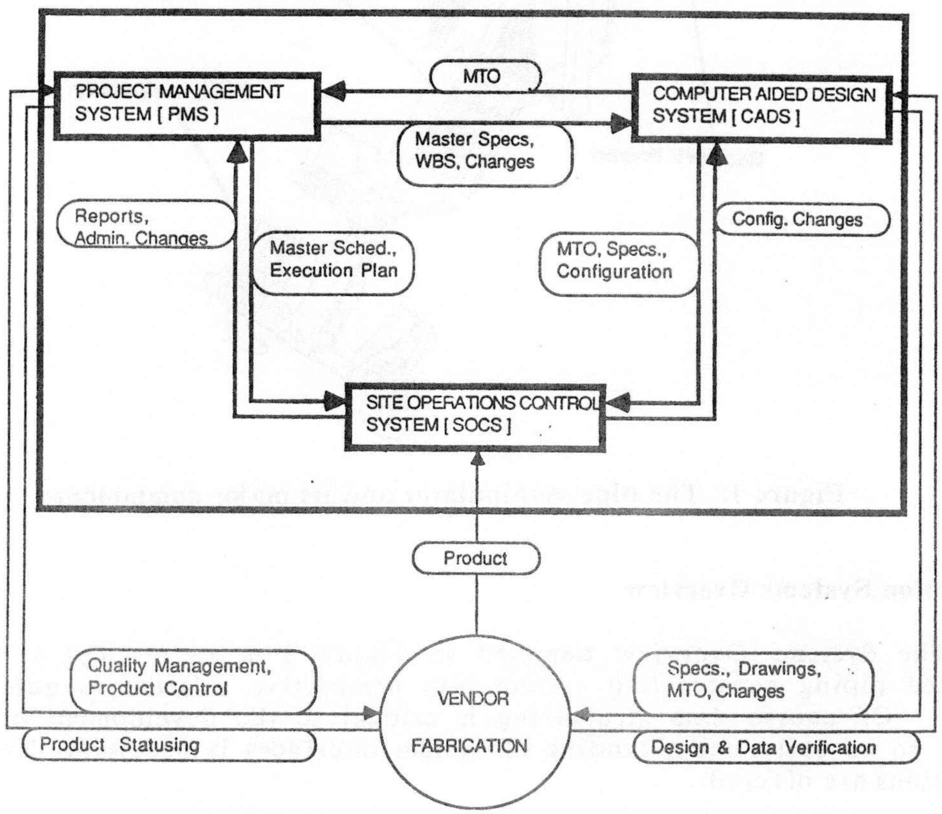

Figure 2: The systems overview

Manipulator Assessment and Enhancements

From an analysis of time-lapse films taken of the pipe manipulator while in operation on a du Pont construction project in Corpus Christi, Texas, researchers have identified four issues for continued investigation. These are listed:

1. Operator/machine functional distinction
2. Location of the operator
3. Operator-machine interface
4. Mechanical improvements

The functional distinction between the operator and the machine is a very fundamental issue. In its current form, the manipulator offers no automated functions - it can be considered a fully manual system. Of course, at the opposite extreme is the fully automated, robot-like manipulator of the future. While this may arguably be the ultimate goal, what steps should we, as researchers, be taking along this continuum or evolution of automation? Figure 3 illustrates the importance of planning in automation research.

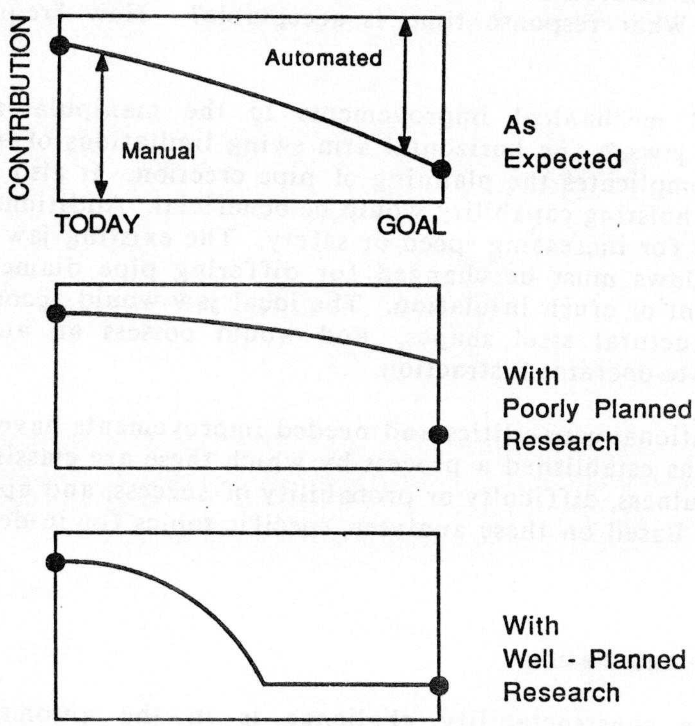

Figure 3: Evolution of Automation

We are still in the planning phase of this research, attempting to define the steps in this evolution. Initially, our attention has been directed toward gaining a better understanding of the operator's role in the existing, all-manual system. To this end, information-decision-action sequence diagrams are being developed. These diagrams will serve as an essential tool in identifying the linkages with other site operations.

With the current manipulator, the operator is located in an elevated basket. There appear to be several problems with this approach: the basket reduces the boom rating and can limit boom accessibility, the boom often blocks operator vision, the boom must be lowered for operator access, the gravity-leveled basket can swing or tilt excessively. Two alternatives to this situation are being analyzed. In the first alternative, the operator is located in the cab of the crane, equipped with monitors linked to targeting cameras. With the second approach, the operator wears a mobile console. Here, several issues remain unresolved, such as the data linkage mechanism, and console portability.

The operator-machine interface centers around the two complex issues of manual manipulator controls and computerized data communications. From analysis of the manipulator, it is apparent that the existing bank of hydraulic control valves must be replaced with a more natural operator-intuitive interface, likely to take the form of an arm-joystick. The issue of computerized data communications can only be addressed after the operator/machine functional distinction has been established. Research questions here center on both information content and information format. What are the minimal information needs? Should they be represented graphically or alphanumerically? What response time is acceptable? How frequently must the database be updated?

Other needed mechanical improvements to the manipulator relate to the manipulator arm or jaws. The horizontal arm swing limitations of +/- 35 degrees is very limiting and complicates the planning of pipe erection. It also appears that the addition of a simple hoisting capability would be beneficial. Additional considerations have been identified for increasing speed or safety. The existing jaw configuration is also problematic. Jaws must be changed for differing pipe diameters and have a tendency to scar paint or crush insulation. The ideal jaw would accommodate various pipe diameters, structural steel shapes, and would possess an automated griping capability to eliminate operator distraction.

Once all additional capabilities and needed improvements have been identified, the research team has established a process by which these are classified according to significance or usefulness, difficulty or probability of success, and appropriateness for academic research. Based on these analyses, specific topics for in-depth research will be prioritized.

Constructability for Automation

The ultimate constructability challenge is in the automated construction environment, in which the human capability for real-time corrective response will be limited to our modeling capabilities and in which reliance on effective project planning and design takes on even greater significance. Accordingly, one of the first objectives of the research team has been the development of a theoretical framework for automation constructability in general, but in particular for piping construction. This framework will offer a structured approach toward constructability analysis in providing a tool for issue identification, prioritization, and analysis.

In draft form, the framework is comprised of both an "intra" framework and an "extra" framework. The intra-framework focuses on the three areas of macro-planning, product design, and operations micro planning. These frameworks correspond to the Project Management System, Computer Aided Design System, and the Site Operations Control System, respectively. The extra-system framework is directed toward the need for modified resource attributes with resources including automated equipment, materials and installed equipment, non-automated equipment and tools, in addition to human resources. Of course, resource interface issues such as the man-machine interface are also to be addressed.

The CATIA CAD modeling system is being utilized as a simulation tool for constructability analyses. It is anticipated that this tool will be particularly useful in better understanding plant layout needs, detailed sequencing and manipulator positioning.

Acknowledgments

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