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CONSTRUCTABILITY FOR SEMI-AUTOMATED PIPING CONSTRUCTION: RESEARCH PROGRESS

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ABSTRACT

This paper focuses on how semi-automated piping construction for process plants may become both technically and economically viable through constructability enhancement. Three major categories of constructability issues are addressed and include problems related to the pipe manipulator, issues associated with the typical layout and design of the permanent plant, and issues related to traditional field operations concerns. Both qualitative and quantitative methods of analysis are utilized. These include use of the Functional Analysis System Technique, creative brainstorming, Pro/Con charts, physical modeling, computer simulation, and operations research techniques.

INTRODUCTION

This paper presents research progress in one of three research areas focused on semi-automated piping construction. In addition to constructability, two other research thrusts focus on enhancement of controls for a pipe manipulator, and the structuring of information systems for site operations control in the semi-automated environment.

CONSTRUCTABILITY AND AUTOMATION

Without reference to construction automation, a widely accepted definition states that constructability is the optimum use of construction knowledge and experience in planning, design, procurement and field operations to achieve overall project objectives [1]. This definition underscores the importance of up-front decisions during project planning, design, and procurement in support of the construction effort.

Certainly constructability has been and will continue to be a key objective for achieving project success. This will be particularly true for projects involving some degree of automation. Under these circumstances, knowledge of the construction process among project planners and designers will be of paramount importance, and the nature of their design product must be responsive to the current capabilities of construction automation technologies. Without such knowledge or responsiveness, both the technical and economic viability of advanced construction technologies will be severely threatened, and technical progress toward cost-effective construction will be stymied. Project planners and designers therefore must ask the question: How does project planning, design, procurement, and field operations need to be modified in order to support the automated field effort and thus achieve the overall success objective?

Beyond underscoring the importance of constructability in the automated environment, it is also important to note that the nature of constructability concerns will be altered with the introduction of automation. At the present time, with mechanized construction, constructability concerns are primarily driven by human capabilities, and specifically, constructor needs or desires for a modified project design or layout, a modified tool or piece of equipment, or a modified sequence of activity. In the semi-automated construction environment, additional constructability concerns will be driven by the capabilities (or rather lack of capabilities) of automated or semi-automated devices. It is unlikely in the foreseeable future that the equipment alone will be fully capable of perfect reaction to the multitude of variables and surprise events so characteristic of construction projects. In replacing manual construction with automated solutions, and in recognizing that such devices will continue to fall short in terms of sensory input, analytical capabilities, and real-time problem solving, project designs and execution plans will have to compensate for the technical shortcomings of automated devices.

Thus, researchers must see all the parts of the system: not only the equipment, but also the human support (the operators), the design of the permanent plant itself, and the construction execution plan. All of these elements will require consideration and will likely be alterered to make the semi-automated system a technical and economic reality.

Finally, the human element in construction will not disappear overnight. The transition from a mechanized industry to a semi-automated industry will occur slowly, and if developments in construction automation are to be successful, researchers and users must acknowledge this evolutionary sequence and proceed accordingly. Thus constructability concerns will also evolve with the technologies.

SPECIFIC CONSTRUCTABILITY ISSUES FOR PIPING CONSTRUCTION

Constructability problems associated with the pipe manipulator include (1), limited joint motions, particularly in horizontal joint pivoting; (2), slow joint velocities; (3), time-consuming mobilization involving outriggers and jaw changes; (4), difficult system control involving eight levers; (5), poor operator location, resulting in safety problems and poor visibility; and (6), desire for additional capabilities.

Serious constructability problems are also associated with the typical layout, configuration, and design of the permanent plant. Specifically, opportunities for enhanced constructability relate to the issues of (1), plant layout density; (2), pipe rack routing philosophies; (3), process equipment arrangement; (4), the design or configuration of individual components, including standardization; (5), the design of preassemblies; (6), methods of alignment and connection; and (7), accessiblility for both piping elements and the manipulator.

Constructability issues related to traditional field operations concerns include (1), the establishment of the overall "path of construction"; (2), detailed sequencing of piping and structural steel erection; (3), manipulator spotting and orientation; and the material handling issues of (4), storage method and location; (5), methods of component identification; and (6), component pick-up points.

METHODS OF ANALYSIS

Both qualitative and quantitative methods of analysis are being utilized to better understand the nature of constructability challenges and solutions. Qualitative techniques include the use of the Functional Analysis System Technique (FAST), creative brainstorming, and the development of Pro/Con charts. Qualitative techniques make use of physical models, computer simulation, and operations research techniques.

FAST Diagrams

The functional analysis system technique is borrowed from the field of value engineering and offers a structured method for defining the hierarchy or tree of objectives/ subobjectives needed to accomplish an established high-order objective. Established high-order objectives include simplify plant layout, simplify component design, increase accessibility, simplify component alignment/connection, enhance equipment/tool configuration, and simplify material handling. Figure 1 is the FAST diagram for the high-order objective of simplifying component design. In viewing the diagram from left to right, the question of "How?" is answered. From right to left, the question of "Why?" is answered. Left-side functions or objectives tend not to be domain-specific. Right-side objectives tend to be piping-specific.

Creative Brainstorming of Solutions

Creative brainstorming is of value in challenging conventional practices and for developing alternative solutions for follow-on analysis. This technique has been used to study the path of construction, alternative pipe rack designs, preassembled piping configurations, and alternative manipulator configurations. Figure 2 illustrates alternative paths of construction for piperack work.

Pro/Con Charts

The Pro/Con chart is a simple but important device for tabulating the advantages and disadvantages of alternative solutions to constructability problems. Such charts have been developed for alternative construction sequences, plant layout, component design, piperack configuration (see Figure 3), and equipment configuration.

Physical Modeling

A 3/8" scale plastic model of the manipulator and plant components has been used to study activity sequencing, accessibility, material handling, and equipment capabilities. For this analysis, study variable values are varied while other variables are held constant. Overall cycle time is then calculated based upon knowledge of manipulator joint movements and respective joint velocities. Cycle time is then interpreted as a measure of efficiency. Figure 4 is a "spider web" sensitivity analysis diagram depicting the sensitivity of cycle time pipe spool length.

Computer Simulation

The "Walkthrough" CAD software developed by Bechtel and resident on a 4D/60T Silicon Graphics workstation has been used for simulation analyses of construction path planning, equipment configurations and capabilities, sequencing, accessibility, and material handling. As with physical modeling, study variables are varied through their range of values while other variables are held constant. Cycle times are again used as an indicator of efficiency. A videotape has been developed to illustrate the use of this analytical tool.

Operations Research Techniques

Operations research techniques offer additional quantitative methods of analysis for studying constructability issues. Dynamic programming, network optimization, and decision trees are currently being explored for the issues of construction path planning, and sequencing of activity.

PRELIMINARY RESULTS

Research activity continues and results to date are only preliminary but some interesting findings have already surfaced:

1. Cycle time is almost twice as fast when the operator is located on the ground rather than in the attached basket.
2. Driving the manipulator forward is four times faster than extending the boom.
3. Current boom extensions are either too short or too slow.
4. Material is best located directly between the manipulator and its final destination.
5. Cycle time for accessibility is three times faster when the access window width is greater than the pipe length.
6. The diameter of piping bears little influence on cycle time with respect to accessibility.
7. Expert systems in conjunction with CAD simulation may serve as a useful tool for assisting operators in construction path planning and sequencing.
8. Cycle time is three times faster when pipe support erection is integrated with piping erection.

CONCLUSIONS

Constructability for automation or semi-automation is critical to the viability of advanced construction technologies. As illustrated in this paper, the specific issues are varied in nature, frequent in number, often complex, and may require radical departures from conventional practice. Also illustrated here is a variety of analysis methodologies that researchers may find valuable. It appears that the ultimate constructability challenge will be associated with the use of automated or semi-automated technologies for some time to come.

ACKNOWLEDGEMENTS

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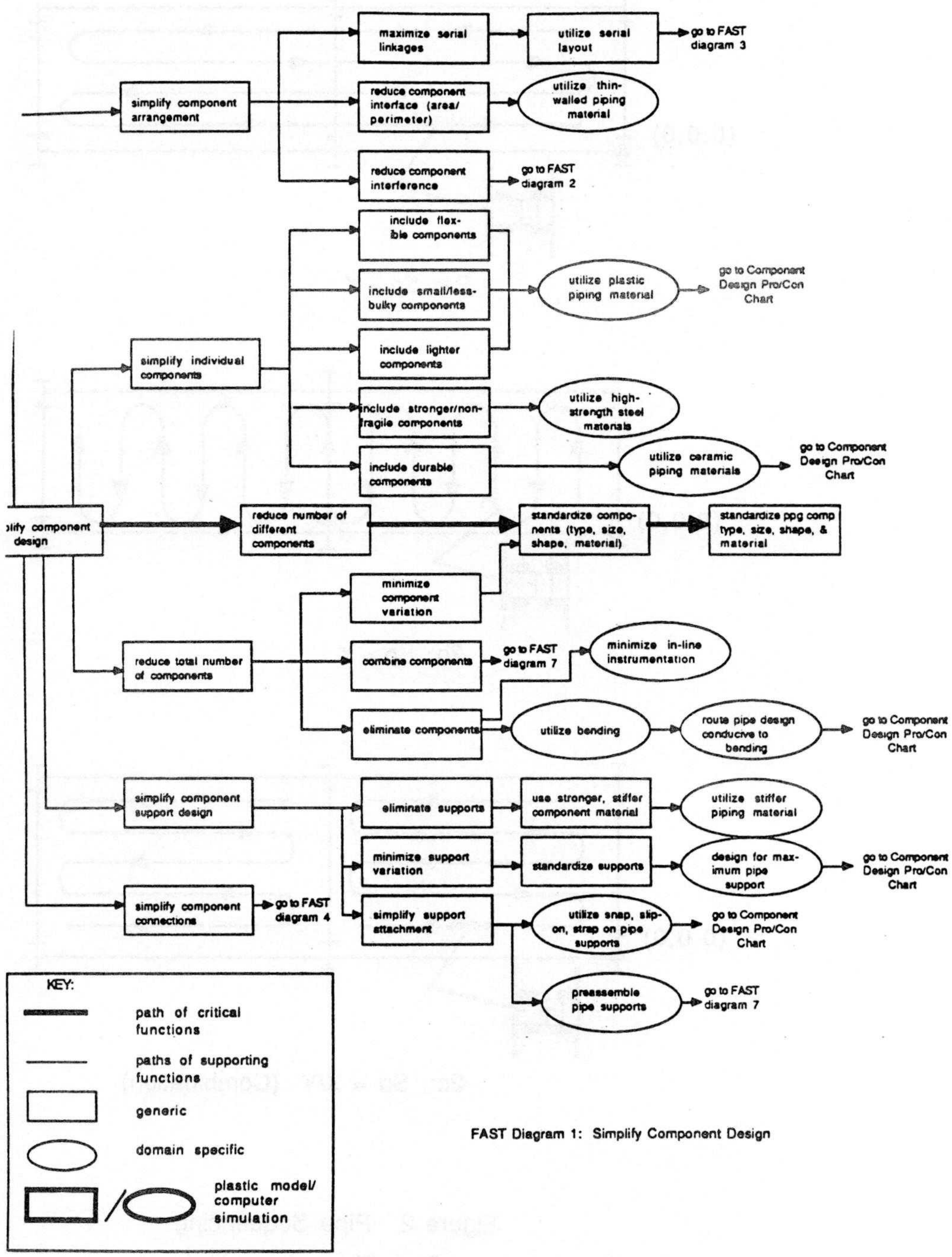
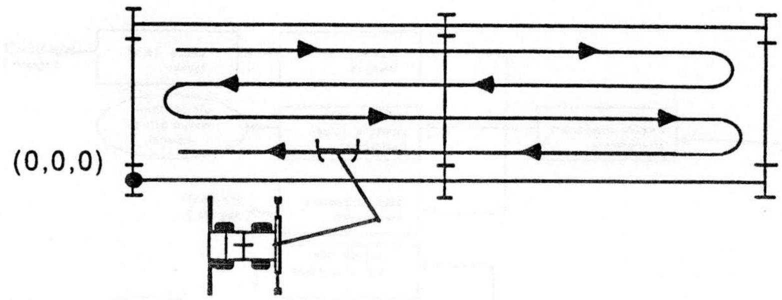
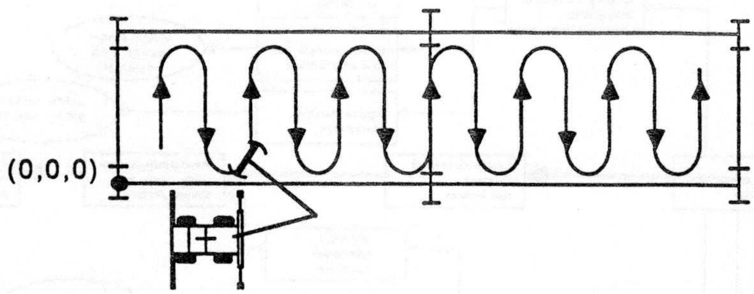


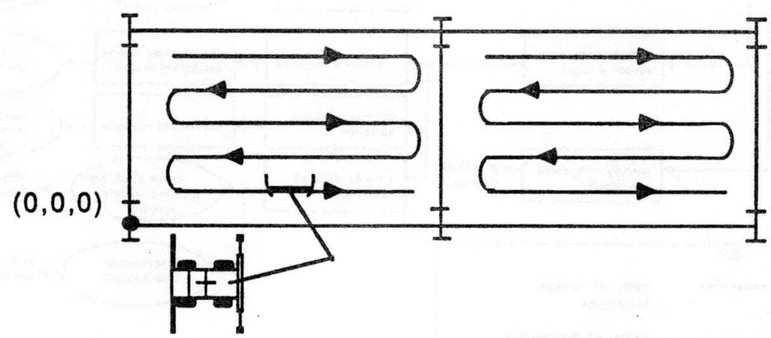
FAST Diagram 1: Simplify Component Design



2a: Sp = X



2b: Sp = Y



2c: Sp = X/Y (Combination)

Figure 2: Pipe Sequencing

Sp = Pipe sequence
Ss = Steel sequence

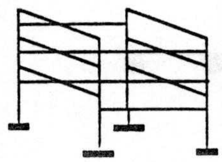
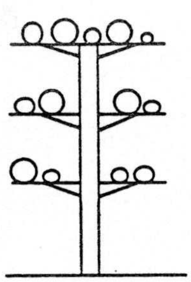
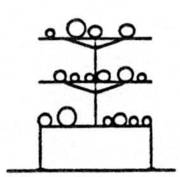
PIPERACK CONFIGURATION	PRO'S	CON'S
Conventional 	- Strong in all directions - Access underneath for maintenance - Support for air fans - Pipe supports are part of main frame (in cast of fire) - Economical and convenient (minimizes steel and cloumn size change)	- Inaccessibility (6'X15' window)
Tee 	- Good accessibility (not for just piping) - Already used for single levels with few (6 to 8) lines, cable trays, tracing, etc. - Could use precast concrete posts (fiber reinforced?) - Could use weld plate for concrete/steel connection - Secondary members could be used to handle lateral loads (every other bay) - Less piping if put equipment under racks - Less expensive to auger holes than pour entire pad	- No strong air fan support - Requires deep foundations due to horizontal loads (similar to transmission tower loads - 30-50' tall, 20' in dia., 10-15' deep) - Loads probably too great for guying - Making post out ot concrete may cause flexural problem (use steel or prestressed concrete) - Making post out of steel causes corrosion problem (need purge) - Secondary members get in the way of lines crossing over the rack - Post takes up space where lines can go down center - Equipment under air fans is a fire hazard - Large utility/flare lines are usually routed at the top (process lines close to equipment) - Columns need 5,000-10,000 psi anchor load to protect sensitive equipment (<1/2" deflections) - High strength steel won't solve stiffness problem (E governs over strength)
Hybrid 	- Good accessibility (not just for piping) - One connection (of upper tee) saves field costs - Shop fab whole top to save field welds - Solves overturning problem of tee - Minimal $ increase over conventional (10-15%) - Could put heavy pipes on bottom and toward center	- Possible uplift problem - No strong air fan support
Outrigger (see figure 1a)	- Good accessibility (not just for piping) - Stable support for air fans - Process equipment could be closer to pipe (underneath)	- Small accessway
Rack as part of equipment support/transport (see figure 1c)	- Good accessibility (not just for piping) - Could be used for maintenance, revamps	- Requires stronger rack design - Requires standardized rack configuration/size

Figure 3: Pro/con Chart for Pipe Pack Design

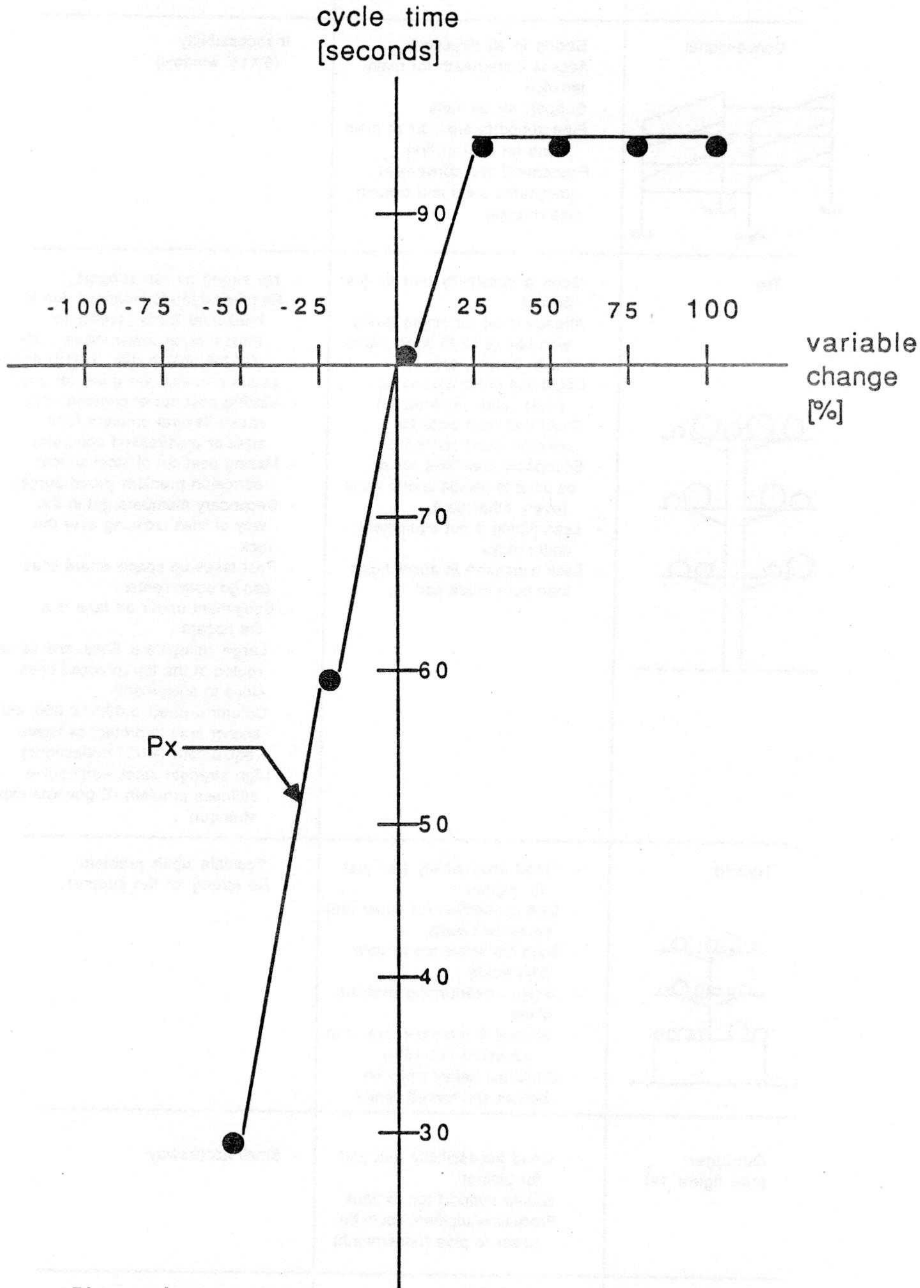


Figure 4:
SPIDER WEB DIAGRAM FOR PIPE CONFIGURATION