USING AN EXPERT SYSTEM TO SUPPORT A PULL SYSTEM FOR CONSTRUCTION PLANNING AND CONTROL

David R. Hillis
Department of Manufacturing
East Carolina University

Greenville, North Carolina 27858, USA

ABSTRACT

A Pull System for planning and control coupled with Just-In-Time (JIT) production creates a well integrated manufacturing operation characterized by exemplary productivity, responsiveness, and low work-in-process. The construction industry is also well suited for this approach using many of the techniques required by a Pull System, such as JIT and team-style supplier-buyer relationships. However, the construction industry often has a difficult time consistently applying these techniques and, therefore, achieving the advantages of a Pull System because of the opportunistic nature of construction projects. Contractors generally have only one chance to plan and control a specific task in a construction project while manufacturers typically have repeated opportunities even in job shop applications. An effective approach for finding and dealing with these opportunities uses an expert system that a) queries the construction teams using various data collection methods, b) identifies the interface between work-done and work-to-do, and then c) recognizes what opportunities are present in time for the management team to act. Therefore, the expert system is able to consult with the site team-leaders to provide an ongoing plan that keeps the organization working on opportunities that will advance the project based on the characteristics of the Pull System. This paper describes how an expert system using the operation characteristics of a Pull System can achieve for construction projects the same benefits that have been achieved in manufacturing operations. An application is presented to illustrate this approach and identify implications for the construction industry.

Introduction

The concepts of Just-In-Time (JIT) and a Pull system for coordinating production operations have significantly changed manufacturing productivity. Schonberger (1986) in his examination of world class manufacturing describes how eighty-four companies have applied these techniques to achieve major improvements in productivity and responsiveness while reducing the complexity of operations. The results they achieved are based on making the dynamics of the manufacturing process more understandable and controllable for the people working in the manufacturing operation.

Although construction projects have many similarities with manufacturing operations, there are some fundamental differences that complicate the direct application of these techniques. The following sections will take into consideration these differences and examine how JIT and a "Pull" system can be applied to a construction project.

A "Pull" System for Controlling Operations

Production control systems in manufacturing are either "Push" or "Pull" systems. A "Pull" system coupled with Just-In-Time (JIT) production creates an integrated manufacturing facility that typically is more productive and responsive than similar facilities operating under a "Push" system. A significant difference between the two is the reduction of Work-In-Process (WIP) on the plant floor (Adam & Ebert, 1989).

The pull method in manufacturing controls the production rate or capacity of the facility to meet current requirements. The systems ability to respond is predicated on maintaining a balance in the rate of production across the entire manufacturing organization. One of the most widely known methods to achieve uniformity in the production rate is the Kanban system. This system removes the ability of the manufacturing operation to store WIP by providing a material handling system that allows only products that are being worked on to be on the manufacturing floor. This is accomplished by using a designated number of containers to define the rate of production. A work center (WC) cannot produce more product unless (a) a container is pulled away to another WC requiring the product and (b) a new container requiring work appears. Until these two conditions occur the WC has no authorization to continue production. Adding containers to the production system provides an incremental method to increase the production rate or "pull" production up (Dilworth, 1989).

The location and contents of the containers on the shop floor provide a visual indication of the status of the production system. The lack of WIP further enhances this visual image. This status indicates where resources should be committed or withdrawn. The decision to allocate these resources is made by the people working on the shop floor. This is one of the major elements integrating the control of the manufacturing operation. In order to achieve an integrated response employees must be able to move quickly into the areas they are needed. Consequently a prerequisite for the success of a "Pull" system is cross trained employees.

The need for a flexible labor orientation and support staff provides a challenging problem for the construction industry's total adoption of the "Pull" system. The team approach with individual members possessing a wide variety of skills is more difficult to implement in construction than it is in most manufacturing situations. This can be due to statutory restrictions limiting specific work to licensed journeymen, to contractual arrangements that a contractor has with trade unions, or to the limited availability of skilled individuals in a geographic location.

A partial solution may be a matrix organization that relies totally on subcontractors to create teams that have the skills needed. In eastern North Carolina (the east coast of the USA) specific manufacturing companies have used this approach on construction projects to create a team based project organization which meets the requisites of a "Pull" system.

There are other aspects of the construction industry that suggest that it is well suited for the "Pull" system. In general these characteristics (Adam & Ebert, 1989, pp. 252-253) indicate an organization's flexibility and capability to respond quickly to actual demand. Examples of these characteristics, as they apply to the construction industry, are:

1. Close team-style supplier-buyer relationships. These relationships are generally the norm for construction projects.

2. Use of pre-construction conferences to review designs and installation methods for major systems.
3. Use of flexible material handling systems.
4. Avoidance of excessive inventories. High inventories mask or hide production problems and adversely impact cash flow.
5. Use of flexible equipment and tooling.

Although this is not a comprehensive list it does indicate a degree of compatibility between a manufacturing "Pull" system and construction operations.

Adapting the "Pull" System to Construction Projects

The objectives for using a "Pull" system in a construction project are the objectives for any control system that is to improve productivity and meet the time commitments of the project (rate of construction) without incurring additional costs. However the "Pull" approach changes the emphasis and simplifies the methodology to achieve these objectives.

The Kanban container is an example of this change in emphasis. It provides for a manufacturing operation a continuous visual status report on where facilities are not being effectively utilized and forces the attention of the organization to those areas. Consequently manufacturing companies that use a "Pull" system are able to make what appears to be a very subtle distinction between what must be done from what can be done in production. Continuously focusing on what must be done reduces delays and other problems which affect productivity. An organization that is constantly able to recognize what must be done has the opportunity to be continuously productive.

Construction organizations have two inherent problems to overcome in the adaptation of a "Pull" system.

1. They generally have only one chance to plan and perform a specific task in a project. Whereas manufacturers typically have repeated opportunities, even in job shop applications, to determine the appropriate sequence and rate of production.
2. A visual real time indicator, the Kanban container, of project status and performance is not suitable for project control.

The means to overcome these problems will require the adaptation of existing planning techniques as well as the use of other techniques such as an expert system.

Planning techniques used by the construction industry are well regarded. Network-based techniques such as CPM and PERT are particularly well known and established for complex long-term projects. Application of network-based scheduling techniques can provide an optimized solution based on time-constrained or resource-constrained activities.

Network planning techniques can also be considered the essence of a "Push" system if used primarily for project control. However the usefulness of network systems for controlling projects has been questioned. The dynamics of the day-to-day situation indicate that constraints used for planning seldom remain the same during the course of the project. It is difficult to define a situation in which only one constraint would apply, particularly with companies that are scheduling and controlling several projects at the same time (Allam, 1988). The heuristic scheduling rules that can be applied to provide meaningful control also require extensive experience and a comprehensive understanding of the current status of the project. Although the network approach may not be suitable for control, it does provide the basis for a control system. The network provides a strategy for completing a project and depicting the obligation that the project organization has for meeting completion dates for specific parts of as well as for the total project. The critical path in the network, therefore, defines the construction rate for the project required by the "Pull" system.

A "Pull" system adapted for controlling construction projects should show the status of the project, the rate of construction, and indicate the work that must be done. Ideally the control system should allow people working on the project frequent opportunities to determine the project status and the work to be done. As indicated, the Kanban container, which performs this function in manufacturing, is not feasible for controlling a construction project; it can be considered as an icon for the concept of a "Pull" system. However, an indicator similar to the Kanban container is needed for project control.

As a means to develop this indicator consider a network as shown in Figure 1 as an example of a project. The progress being made on the project involves several activities and consequently establishes an interface between work done and work to do. The nodes that are immediately ahead of this interface can be considered as the Kanban (card) "Pulling" this phase of the project. The activity that lies on the critical path establishes the rate at which the interface should progress towards the active nodes of the project. The advancement of the interface (involving activities leading to one or more nodes) is expected to support the activities on the critical path. All activities leading to a node should be completed concurrently. Any work on an activity that has remaining slack time would be analogous to creating WIP, work that is not required. Therefore the assignment of resources should be made to activities that do not have slack time. Allocation of resources that exceed the critical path rate will create slack or the equivalent of WIP.

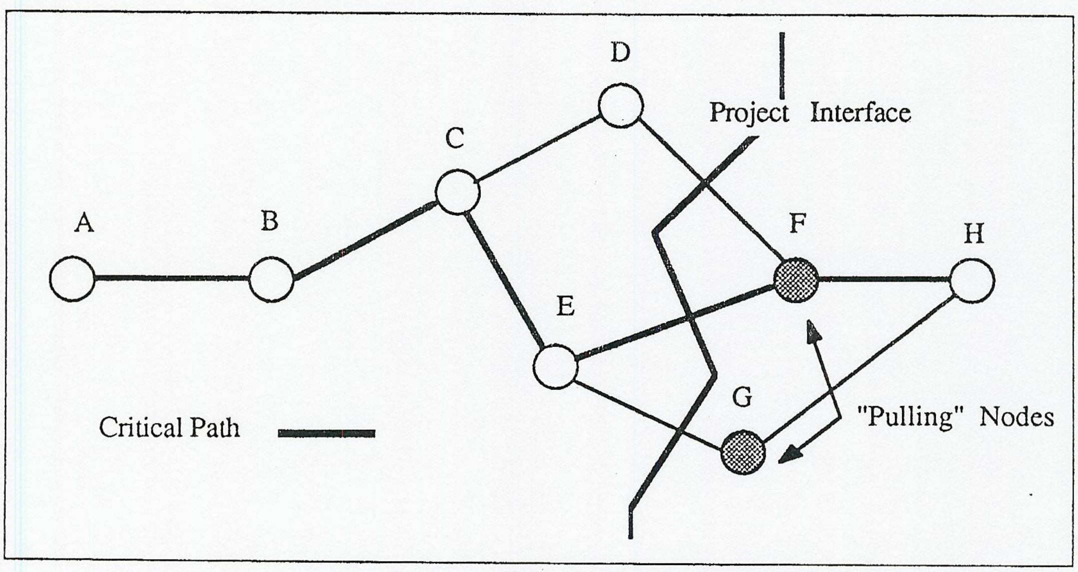

Figure 1. The Interface, Work done / Work Required.

Defining the location of this interface is what most construction supervisors are intuitively doing as they effectively direct and control the work on small projects. On large projects involving several supervisors the overall location of the interface, the rate of advancement relative to the critical path, and identification of the work required are all difficult to define on a continuous basis. To accomplish this an expert system can be developed, given these requirements, to provide the necessary information.

Application of an Expert System

To meet these requirements the expert system must: (a) identify and define the location of the interface between work done and work to do, (b) list the work required to be done, and (c) provide an indication of project status and performance. This information however does not offer the same visual image that the Kanban system presents. Therefore a graphic image has to be developed for the site team-leaders. The expert system needed to provide this information and image is outlined below.

An expert system meeting these requirements can be achieved by a variety of approaches. The discussion here is predicated on using a MS-DOS computer and AI software such as Texas Instrument's Personal Consultant Easy.

In general an expert system needs:

1. A body of knowledge that contains facts, rules and representations about the way the project will be completed.
2. A mechanism to perform the inference procedure that will produce a solution to a particular problem.
3. Supplemental software that will work with the inference procedure and knowledge base to facilitate the input of information and to provide graphics for output from the expert system.

Although there are many ways to express knowledge in an expert system, the most common form of knowledge representation is with rules. This is also the method used by Texas Instrument Software Personal Consultant Easy. A rule is a combination of facts, functions and certainty factors in the form of an if-then statement. The inference engine, the mechanism to perform the inference procedure, applies the knowledge base (rules) to the information supplied on the current status of the project (Texas Instruments [TI], 1987).

Expert systems can be either data driven (antecedent) or goal driven (consequent) to develop a problem solution. A data driven or forward chaining system would react to the project using the current data and develop several strategies to establish the interface and the work required (Ranky, 1986).

The alternative is to use a backward chaining method to reason and interpret the values contained in the rules. The approach developed in this paper uses backward chaining, which enables the system to determine the location of the interface and the work required to be done after (a) the active nodes in the network have been stipulated and (b) new values are entered to update the knowledge-base.

Using a relational database to supply these values to the expert system provides several advantages.

1. It offers a variety of ways, many being user friendly, to collect data on the work done.
2. It provides a structure or template that can be applied and / or modified for similar projects.
3. Erroneous data can be verified or trapped before it is used by the expert system.

A further enhancement to the database would be to use bar codes as a means for collecting data. Bar coding provides a rugged data collection system that can function reliably in harsh work environments (American Production and Inventory

Control Society, [APICS], 1983). The ease and accuracy of data collection is critical if the current status of the project is going to be continually available.

The generation of the interface and the work required is relatively easy for an expert system provided that the knowledge base has sufficient detail in terms of rules to locate the interface and provide a meaningful listing of work required. Generating a visual image of the project status is slightly more involved. The arrangement of the knowledge base follows the precedents established by the network. However the output or image will not be a planning network but a Gantt chart which will emphasize the activities that are "Pulling" the project. Activities can not "Pull" the project until the interface passes through the activity's slack time and engages the work to be done. The location of the interface on the Gantt chart, therefore, provides a visual representation of the project status which is shown in Figure 2. The activities ahead of the interface are shown with a dotted line. These activities have a starting point defined by a "Pulling" node. In a "Pull" system these would be considered as "action buckets" for the Material Requirements Planning (MRP) being used to support the "Pull" system (Adam & Ebert, 1989).

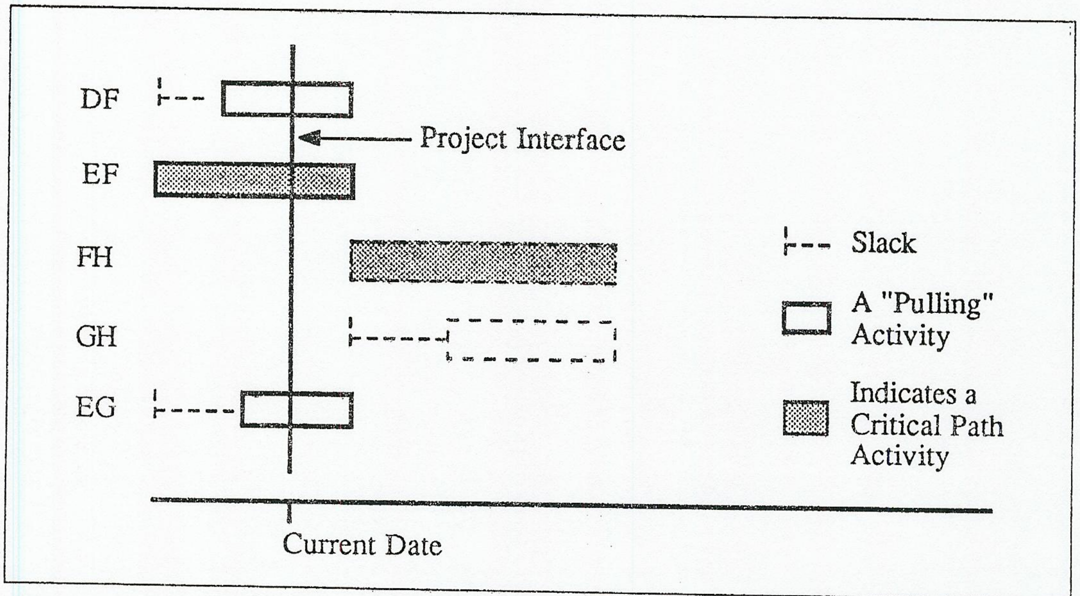

Figure 2. The Project Status showing uniform performance for the entire project

A vertical line for the interface indicates that the project is advancing at a uniform rate. If the line coincides with the current date, the project is maintaining a rate equal to the critical path requirement. Irregularities in the line indicate that the rate is not uniform across the entire project. Strategies and methods used to control and direct the project would be based on restoring a uniform rate represented by a vertical line. Therefore the intersection of the vertical line with a "Pulling" activity becomes a construction project Kanban container.

Using the System to Control the Project

The operation of this system will require a project survey (the collection of data) each time the interface is to be established. The ability to detect movement of the interface is dependent on the precision of the project model that has been created in the knowledge base. Increasing the detail contained in the model allows for frequent detection of interface movement and rate disparities in the "Pulling" activities.

Opportunities to shift work crews and knowing when new activities will be "Pulling" provide the means to improve productivity on the project. Therefore the vertical line or project status image has value for the daily coordination and allocation of resources.

The listing of work required may not be needed daily. The frequency would be determined by the site team-leaders. The listing provides a "look ahead" to identify other opportunities, form new work teams, and expedite materials for nodes ("action buckets") that are about to "Pull" the project. The strategies to be developed for advancing the project are the direct responsibility of the management team. The expert system's responsibility is to supply a situational analysis, not to offer strategies.

Implications for Use

Because the "Pull" system conceptually does not provide for any slack or for "working ahead" (this creates WIP) it places a significant amount of pressure on the teams involved in the project to maintain the rate - keeping the interface straight. Therefore the construction organization has to provide the flexibility that is being intentionally forced out of the project through the elimination of slack time by (a) being able to reform work teams, (b) using teams that have the variety of skills needed to perform all the activities in a major phase of a project, or (c) using a combination of both.

Having the skills required in the work force is the most difficult obstacle to overcome in the adaptation of the "Pull" system to the construction industry. It can be accomplished, although the method used in one region may not be applicable in another area.

An implementation of the "Pull" system on a construction project was observed by this writer. A manufacturer of automotive components constructed a 20,000 square foot addition to its existing plant and simultaneously rearranged equipment in the entire 120,000 square foot plant with normal manufacturing continuing during the project. This project was small enough to allow the team leaders which included outside contractors to operate without an expert system. The project status and the work required was established entirely during team meetings which were held several times a week. The flexibility of the work force was created by drawing the required individuals from specific contractors whose people had the necessary skills to form work teams. The project management was supplied by the manufacturing superintendent who has abilities in developing and supporting a "Pull" system in manufacturing organizations. The size of this project was modest but it demonstrated the application of a "Pull" system in project management. The benefits achieved were indicated by the plant's ability to continue operations during this period as a JIT supplier for the automotive industry and carry out the project on budget.

The commentary of his experiences provided many of the insights for this paper. The factors identified also supplement the characteristics specified by Adam & Ebert (1989). Essentially the critical factors that must be present to apply a "Pull" system to a construction project are:

1. Flexible or cross trained work teams for carrying out the work of the project.
2. A management organization that supports the team with equipment and materials.
3. Establishment of the "Pull" system concept from the top down.
4. A clear understanding among team leaders of the work required.

5. An easily understood image of the current project status for those working on the project.

A question can be raised about the need for an expert system to assist in the control of a construction project. The case described above provided a level of complexity that required the manufacturing superintendent's full time. The detail for manually determining the rate the project was advancing and identifying the work that was required to be done absorbed the majority of the manager's time. His work did provide the teams with the information needed to detect the opportunities and advance the project to meet the requirements of the company. A slightly larger project would be near or at the threshold of utilizing an expert system advantageously.

Conclusions

A "Pull" system can be adapted to the construction industry. The improvements in responsiveness and productivity that have been found in manufacturing also appear to be available for construction projects. The essence of a "Pull" system is continually to force the organization to work on only what must be done and not on what can be done. The control system in manufacturing accomplishes this in many ways, the Kanban container being the most widely known. To achieve the same simple indication of status and performance in construction requires a different approach. The method proposed provides a visual image on project status and performance. This approach can be accomplished manually; however, on large projects, the use of an expert system will make this approach more feasible.

References

Adam, A. E. & Ebert, R. J. (1989). Production and Operations Management (4th ed.). Englewood Cliffs, NJ: Prentice-Hall.

Allam, S. I. (1988). Multi-Project Scheduling: A New Categorization for Heuristic Scheduling Rules in Construction Scheduling Problems. Construction Management and Economics, 6, 93-115.

American Production and Inventory Control Society. (1983). Bar Coding Reprints. Falls Church, Virginia: Author

Dilworth, J. B. (1989). Production and Operations Management (4th ed.). New York: Random House.

Kusiak, A. (1988). Artificial Intelligence Approach to Production Planning. In A. Rolstadas (Ed.), Computer Aided Production Management (pp. 149-166). New York: Springer-Verlag.

Ranky, P. G. (1986). Computer Integrated Manufacturing. Englewood Cliffs, NJ: Prentice-Hall International.

Schonberger, R. J. (1986). World Class Manufacturing. New York: The Free Press.

Texas Instruments Incorporated. (1987). Personal Consultant Easy Reference Guide. Austin, Texas: Author.