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REAL WORLD APPLICATIONS OF CONSTRUCTION PROCESS SIMULATION

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ABSTRACT

Construction simulation has been an academic tool since the 1960's. There are over 20 construction programs in the U.S. and Canada that offer construction simulation as a course at both the graduate and undergraduate levels. Although simulation has proved a valuable teaching tool in the academic setting, use by practicing professionals has been limited. The construction industry has been reluctant to consider this tool as a definitive aid for resource optimization and productivity improvement.

This paper presents an example of the successful use of simulation by a large international construction company. The objective of the paper is to better understand what factors have enabled this company to continuously and successfully implement construction simulation on many of its projects.

1 BACKGROUND

In the academic environment, the CYCLONE methodology is used widely as a vehicle for introducing students to the concept of construction simulation. There are over 20 universities with regular courses that use a CYCLONE based or similar simulation tool. The application of simulation has been used extensively in the evaluation of construction projects. However, its use has been primarily for ex-post or appraisal types of analysis since the tool has not typically been used for decision making during the construction of real projects. Nevertheless, the results obtained from these academic analyses have been promising (Rodriguez 1998) Academics have also used simulation for the optimization of generic construction operations without reference to a particular project.

In order for a construction company to use a simulation tool, the methodology has to be presented in a very simple and graphical context. Pictorial and schematic tools are easily accepted. In contrast, if the methodology appears to be too theoretical or analytical it will be avoided by construction practitioners.

Currently 3D-modeling is the trend in the simulation area. However, developing 3D models of construction operations is very complex and time consuming. In general, the study of construction operations requires a tool that provides solutions without requiring the input of copious amounts of data.

Random and sporadic attempts to interest the construction industry in simulation have not proved successful. Usually, construction contractors work intuitively based on experience with similar jobs and situations. Most construction contractors feel that analytical tools restrict use of their intuitive approach to problem solving. (Halpin 1998)

This paper shows how simulation can be successfully applied to different types of construction operations. However, the types of operations that can be simulated need to be cyclical or repetitive in nature. Many construction operations are cyclic in nature and have a great potential for improvement through the use of simulation.

2 THE DRAGADOS EXPERIENCE

PROSIDYC is a system simulating construction operations jointly developed by the Planning and Methods Unit (PMU) of Dragados y Construcciones, Madrid, Spain (DRAGADOS); and the Division of Construction Engineering and Management at Purdue University (PURDUE).

PROject SImulation Dragados Y Construcciones (PROSIDYC) is a computer based system for analyzing construction job site production processes. It is used to improve productivity in the field by studying resource utilization and cycle times and identifying opportunities for production improvement. PROSIDYC uses the CYCLic Operations NEtwork (CYCLONE) modeling format originally developed by Halpin (1973, 1992a, 1992b). A set of graphical modeling elements is utilized to develop a network model of the process of interest. The model identifies waiting or delay states as well as active productive states. The computer program allows the modeler to identify resources which are under utilized and bottlenecks in the process under study.

The use of this approach has achieved 100% success in productivity improvement on the processes studied. Improvements range from 30% to 200%. Data support the fact that for every hour of analyst time used. a saving of $2,000 is realized. Therefore, for 100 hours of engineering time invested a saving of $200,000 is achieved.

The program has been used on over 30 projects including, tunnels, maritime projects, dams, highways, etc. Examples of these projects are:

- A precast factory: PROSIDYC was used to analyze and improve the manufacturing of 29,950 precast segments for a 5.85-km sewer collector. An improvement of 44% was obtained. The production rate increased from 128 segments per day to 216 segments per day.
- Construction of floating caissons of large dimensions (42m long, 16m wide, 16.5m height). The simulation of the construction processes allowed the calculation of the precise volume, allowing a very important increase in the final production (45%).
- Improvement of the production of a concrete plant. A concrete plant was bought from a supplier who claimed a production rate of 50 cubic m/hr. In its first use the production did not exceed 33 cubic m/hr. After implementing the improvements indicated by the program, the production rate reached a value of 43 cubic m/hr, a 30% increase.
- Concrete pouring in a Roller-Compacted dam. The application of PROSIDYC provided the optimization of all the activities that were to be done in every layer.
- Renovation of train tracks without traffic interruption. The simulation program was applied to coordinate the work. The results doubled the initial estimates for the daily production.
- Tunnel excavation. Simulation was done to improve the operations considering the available space. Improvements of 20% in the excavation cycles were obtained.

3 THE PROSIDYC APPROACH

The PROSIDYC approach is innovative in forcing the manager to focus on the process level factors which control production rates at the job site. As noted by Edmundo Balbontin, "the Dragados Group is founded upon innovation with particular emphasis on careful analysis of field operations to achieve improved productivity. Because of this, the company has developed a mindset in which managers do not only think in terms of days, but in minutes and fractions of a minute." (Rodriguez 1998). Dragados views its field operations from a manufacturing perspective seeking to introduce repetitive activities into the construction process.

PROSIDYC (and its CYCLONE based modeling approach) allows the analyst to experiment with various site layouts, sequences, and resource combinations to achieve the best production at the most cost-effective level. PROSIDYC is superior to pictorial simulations since it focuses on the interaction of resources and constraints associated with the site and the sequence. Since it is based upon a schematic diagram of the process. it can be quickly reconfigured for analysis of varying process alternatives. It triggers innovative thinking regarding modifications to the productive process. Through computer simulation the planner can experiment with and quickly evaluate process alternatives in an iterative manner. It provides a tool in terms of which the process can be designed and redesigned until it has achieved maximum production and minimum cycle time.

In the case of the precasting operation for tunnel liner sections of a large server collector project, the original operation achieved 64 precast elements per shift based on a production cycle of 179 minutes per cycle. After six redesigns and an increase in workers from 18 to 21, the production was increased to 108 elements per shift. The cycle time was reduced to 120 minutes per cycle (Balbontin 1998). A typical schematic model for this process is shown in Figure 1.

The schematic modeling format of PROSIDYC can be easily understood by field managers. Output includes a multi-activity chart which can be handed directly to the field crews so that they can understand the work sequence in a simplified bar chart format. In the project noted above, top and middle managers easily understood the information presented both in the models and the charts. The simulation was a persuasive tool. Based on presentations regarding the simulation and the improvements possible field management of the sewer collector project adopted the redesigned process. Within two weeks of changeover, the target production of 108 elements/shift (216 elements/day) was reached and maintained.

In order to insure that managers understand the potential of simulation modeling, all project management personnel take a 3 day course on processimprovement and simulation. Managers are sensitized to the technique and encouraged to identify candidate processes which can be improved. Incentives are provided since savings achieved by analysis and improvement are shared in whole or in part with the field managers.

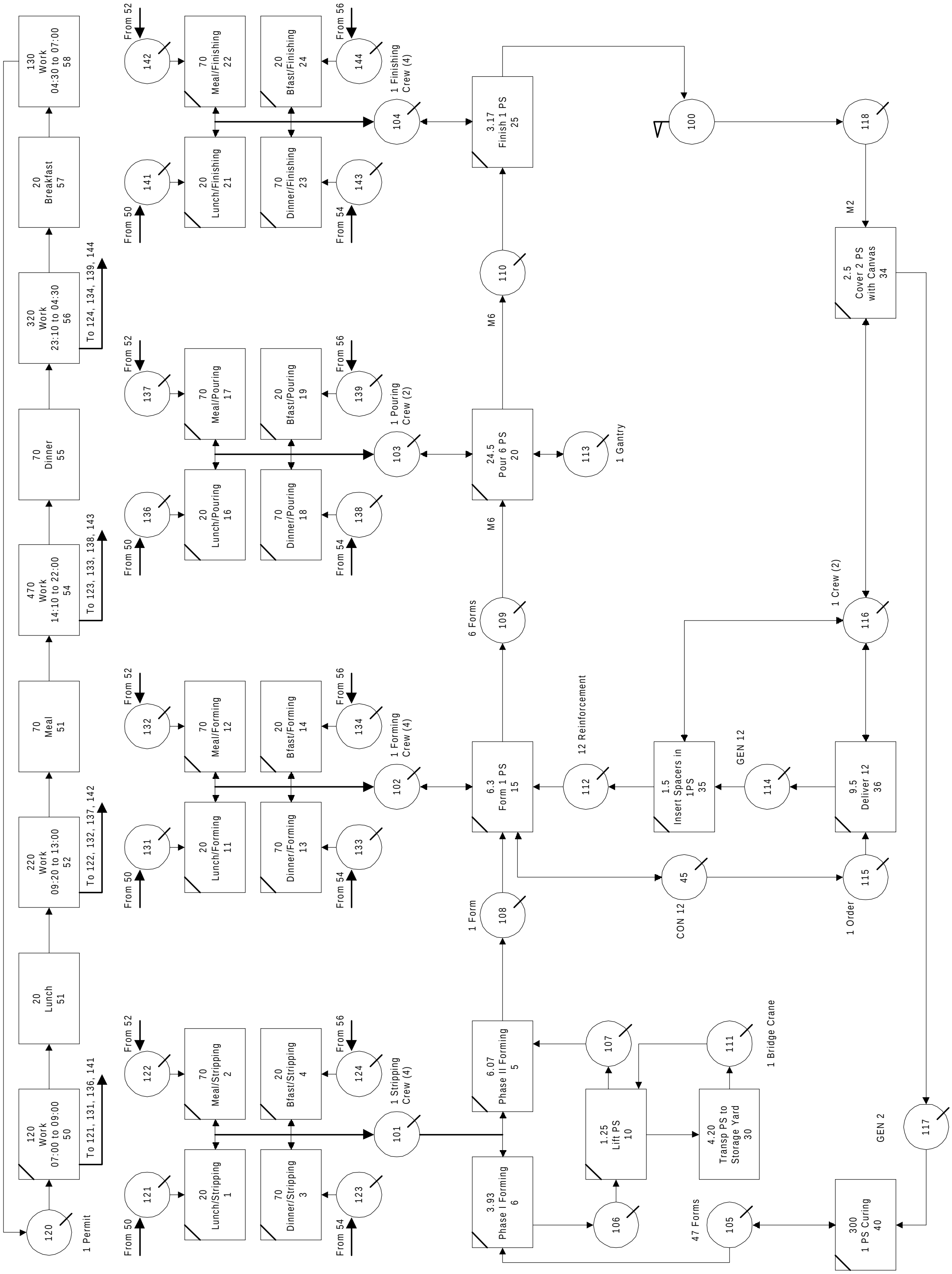

Figure 1: A Schematic Model of Precasting Operation

4 THE DEVELOPMENT PROCESS

The development and implementation of PROSIDYC has been an ongoing activity between DRAGADOS and Purdue over the past 10 years. In the mid 80s DRAGADOS tested a number of simulation programs with a view to modeling construction operations. It was decided to adopt the CYCLONE methodology and its PC version: MicroCYCLONE. Two factors led to the adoption of the CYCLONE format. First, the program was able to faithfully reproduce reality. This proved a problem with programs using formats other than the CYCLONE format. Secondly, the program and process modifications proposed had to be easily understood by the project and field managers. The schematic format of the CYCLONE system and the flow charting characteristics of the methodology facilitated its quick comprehension by site personnel.

The CYCLONE system of modeling construction processes has been in constant evolution during the past 20 years. In 1988, DRAGADOS personnel contacted Professor Halpin at Purdue and discussed the possibility of implementing the program within its Planning and Methods Unit (PMU). During the past decade, Professor Halpin has traveled to Madrid frequently to work with members of the PMU and assist in adaptation of the MicroCYCLONE program for use by DRAGADOS. Two graduate students also traveled to Madrid to work within the project management area and assist in the implementation of the program within DRAGADOS. This work was supported in part by the International Programs office at Purdue. Primary support for this activity was funded by the Technical Division of DRAGADOS and its Sr. Vice President, Juan Manuel Moron.

The cordial relationship established between both parties has led to the creation of PROSIDYC. This modeling framework includes a number of innovations including:

1. A simplified and stylized input module.
2. Simplified linking formats for model construction and representation.
3. A resource module which expedites presentation of information about the saturation and production capacity of each resource and displays bottlenecks to assist in assessment and identification of improvements to the process.
4. Preparation of a multi-activity chart which explains in detail how the work should be organized and which is easily understood by the project chain of command.

The interaction between Purdue and DRAGADOS is continuing with projects in progress to improve the PROSIDYC system by utilizing an improved Windows interface.

5 A PRACTICAL APPLICATION: FLOATING CAISSONS

Floating caissons are prefabricated concrete box-like elements with cylindrical cavities or cells that are used for marine and harbor projects such as: ports, breakwaters, wharves, berthing facilities and docks, dry docks and slipways, fishing ports and marinas. Caissons are built with special DRAGADOS facilities called “Floating Docks.” See Figure 2. The floating caisson dimensions are customized to project requirements within certain limits (Martinez and Rodriguez 1997.)

The project considered here involved the construction of 3,805m of breakwaters and 996m of wharves to expand the area of the Valencia port. The new area created between these two structures was 120Ha (297 acres) and it required more than 17,000,000 cubic meters of dirt fill.

The 996m of wharves were constructed using 26 floating caissons. Each caisson had the following dimensions: 42m long, 16m width, and 16.5m height. Its concrete volume was of 2,857 cubic meters. It required 116,27 metric tons of rebar and had an approximate weight of 10,560 metric tons. The caisson consisted of a concrete solid slab of 0.6m height, followed by a concrete block with 62 cylindrical cavities, 3.8m diameter, to reduce its weight.

The simulation of the caisson fabrication involved four main processes:

1. Concrete Mixing and Pumping.
2. Slab pouring.
3. Upper caisson pouring.
4. Retrieval of support bars.

Besides the traditional materials required in concrete construction, the resources involved in the fabrication operation included:

- A floating dock that holds two concrete delivery pipes and a crane.
- Two auxiliary floating platforms.
- A concrete batch plant.
- Two concrete pumps of 50 cubic meters/hr capacity.
- A gantry crane.
- Loaders.
- Air compressors.
- Pneumatic pumps.
- 34 workmen per 3 shifts.

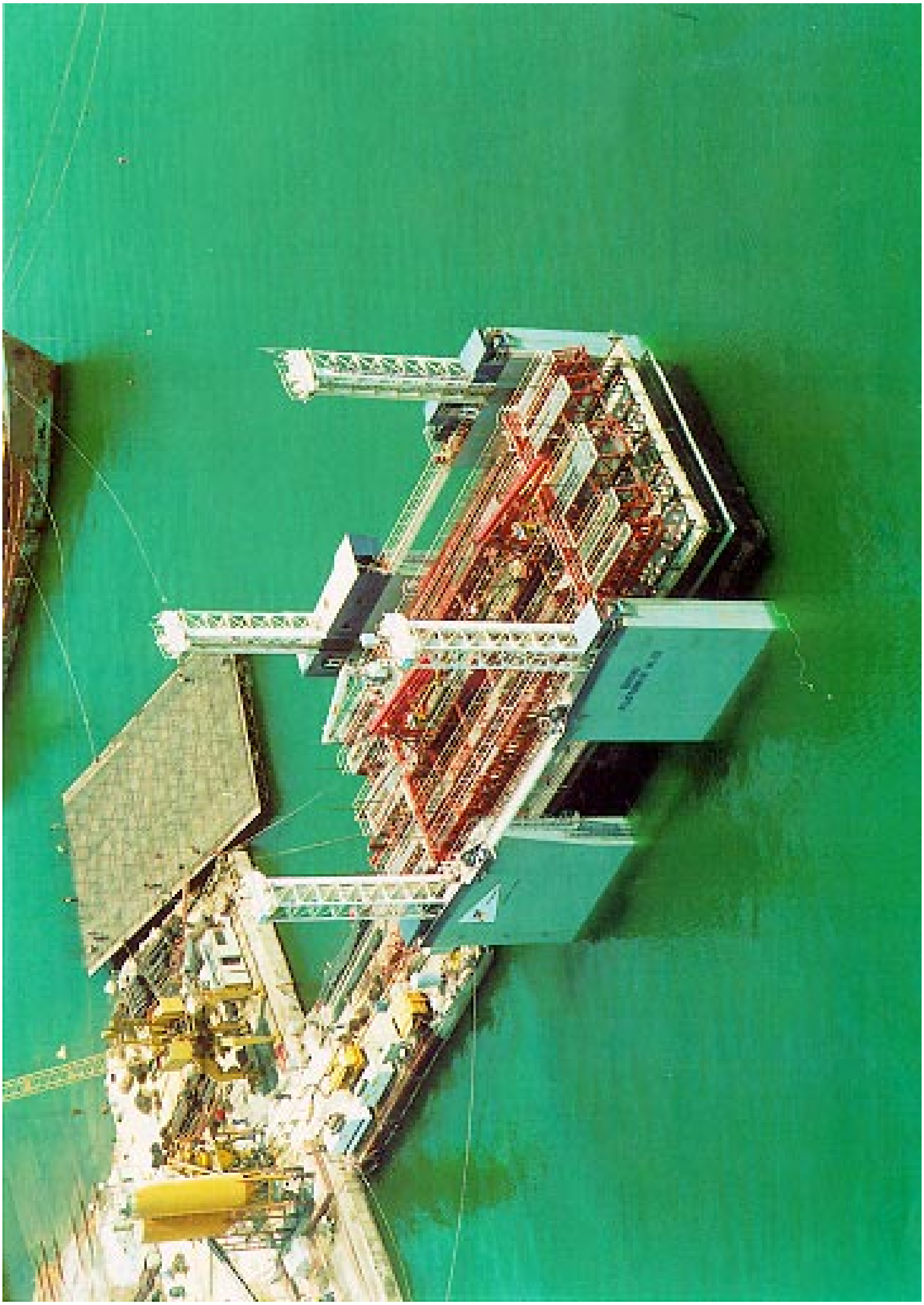

Figure 2: Floating Caisson

Of the four main processes considered the Upper Caisson Pouring was chosen for optimization. This was the most relevant process based on the amount of work involved. It represented 85% of the concrete being poured and an estimated 74% of the fabrication time.

The shaft of each caisson was poured with two pumps of 50 cubic meters/hr capacity. A concrete plant prepared the concrete and discharged it to a hopper that fed the pumps. Sliding formwork was used where its support structure interfered frequently with the pouring activity. This required reconsideration of the capacity of the hopper and separation of the pouring activity from the hopper pumping activity to the hopper.

The analysis of the process cycle was conducted when the third caisson was under fabrication. The recorded total fabrication time for the first two caissons averaged 153 hours - 39 hours above the established 114 hour planned duration. An analysis of the process revealed that its productivity was 35.7 cubic meters/hr, considerably below the 65 cubic meters/hr that is possible to produce and pump.

Model considerations:

1. The upper caisson was poured in layers of 25cm (38 cubic meters). For this volume, each pump must discharge 19 cubic meters of concrete, equivalent to 12.7 batches.
2. The concrete delivery pipes had to interrupt their pouring process 12 times each, due to the steel beams of the working deck that restrict their free movement. This meant that each delivery pipe discharged approximately 1.1 batches before changing its position.
3. The concrete plant prepared batches that were directed to each pump as needed.

With the application of the PROSIDYC program, two alternatives were proposed:

1. Double the capacity of the pump hoppers allowing them to receive, two batches each from the concrete plant. The results reported from this alternative were 42 cubic meters/hr, which represents a 24% increase in production.
2. Doubling the capacity of the pump hoppers (Alternative 1) plus reducing the number of delivery pipe positions from 12 to 8. This could be done by modifying the shape of the working deck structure beams. Instead of using a beam with a rectangular section, a "V" section could be used in order to have a large area to pour concrete without interruption. The results of the simulation indicated a productivity of 47 cubic meters/hr. This yielded an improvement of 38% from the original process and 14% improvement when compared to alternative 1 (Martinez and Rodriguez 1997).

A cost-benefit analysis was conducted to compare the cost of the modifications of the working deck to the benefits that could be received by an improvement of only 14% of alternative 1.

6 INNOVATION IN THE CONSTRUCTION INDUSTRY

The National Science Foundation and the Construction Industry Institute sponsored a workshop in Austin, Texas in May of 1997. The workshop addressed the question, "How do we use research to improve the engineering and construction industry?" One of the major topics discussed was the barriers typical of the industry which obstruct the acceptance of innovation and new technologies. One of the panels addressing the topic, "How can the industry learn from research?" reported on some interesting points regarding acceptance of new ideas by the EPC industry (Oberlender 1997).

To implement new ideas within a design/construction company, the following situation must develop:

- The new idea or concept must be compatible with the "company culture."
- There must be a champion who will demonstrate the advantages to be achieved by the new idea and who will push for its adoption.
- The new concept or idea must yield significant benefits for a relatively small amount of time, manpower, and capital committed.

These "Stars" must be in alignment. If the new idea is relatively simple and easy to disseminate, so much the better. In order to overcome the barriers of accepting innovation, these conditions must obtain:

- A compatible company culture.
- An internal or external champion.
- High cost/benefit ration.

In the DRAGADOS example, all of these points were in place. The company's 'manufacturing' approach to construction made the use of techniques to save "minutes and fractions of minutes" topics of immediate interest. This emphasis on achieving small time savings repeated thousands of times is key to the company culture. That is not to say that large savings are neglected. However, the company is very sensitive to the large potential for profit at the level of the cycles and repetition at the job site.

The planning and methods unit acted as the internal champion for the use of simulation. Finally, the payoff in the form of $2,000 in savings for every engineer hour invested made field managers very interested in using new techniques. Since bonuses and personal success are tightly tied to production, field managers were motivated to work with the planning and methods unit to improve production.

7 CONCLUSIONS

DRAGADOS has achieved improved productivity on all of the projects on which PROSIDYC has been used. Productivity improvements have ranged from 30% to 200%. This has resulted in reduced project delivery time and increased productivity on all of these projects. Over 100 process models relating to 30 projects have been developed using PROSIDYC. Project delivery time reductions have been achieved on all of these projects. This has led to significant time and cost savings which are estimated to be in excess of $10 million.

The potential for further improvements in productivity is virtually unlimited. Models developed for one project can be adapted and reused on other projects. This leads to a database of expertise which focuses management's attention on searching out productivity improvements. It supports the concept that process design and improvement is a way of life. This has had a major impact on managers in the field and supported a company culture in which improved productivity is an area of daily emphasis within the firm.

This same mindset has great potential for the construction industry in general. Emphasizing design of field processes to achieve repetition leads to improved productivity and expedited project delivery without sacrificing quality and functionality.

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