AC 2007-419: LABORATORY LEARNING OF THE BENEFITS ARISING FROM DETAILED PRE-PLANNING OF CONSTRUCTION OPERATIONS

John Hildreth, Virginia Tech

Michael Vorster, Virginia Tech

Laboratory Learning of the Benefits Arising from Detailed Pre-Planning of Construction Operations

Abstract

Construction operations can be categorized as either routine and repetitive or unique and complex. The means of developing an understanding of operations in each category differs. An understanding of routine and repetitive operations is best developed through analysis of field operations. Unique and complex operations by their very nature have not been constructed in the field. Therefore, an understanding of such operations can be developed through a pre-planning process of first "building on paper." A laboratory session was incorporated into a construction means and methods course to demonstrate the benefits of pre-planning construction operations. Students used the K'NEX construction system to build a replica of the Tower Bridge. By design, some groups pre-planned their operations, while others did not. The value of pre-planning was evident through observation of their performance.

Introduction

Construction operations can be categorized as either "routine and repetitive" or "unique and complex." Regardless of the category, the ability to analyze and improve the operations represents a competitive advantage for the performing party. The category does influence the methods and techniques employed to develop an understanding of the subject operation. Traditional techniques of field operations analysis are applied to improve routine and repetitive operations. Unique and complex operations do not afford the luxury of analyzing previous performance. Such operations are improved by first "building on paper" through a detailed operations pre-planning process.

A construction means and methods course is an integral part of a construction engineering and management education program. The objectives of the course should address the features and performance characteristics of construction equipment, as well as the principles of operations analysis and improvement. The senior level means and methods course at Virginia Tech was recently restructured to include a laboratory component to demonstrate the principles of operations analysis, methods improvement, and field data collection. A specific laboratory exercise was performed to demonstrate the benefits of detailed operations pre-planning for unique and complex construction operations. The exercise was well received by the class, successful in revealing the benefits of pre-planning, and made a lasting impression on the students.

Operations Improvement Techniques

Techniques for improving construction operations are either applied during construction or prior to construction. Field operations analysis techniques are applied to ongoing operations to record data, analyze performance, identify problems, and devise solutions[1]. Prior to operational performance, a formal pre-planning process may be employed to gather information, develop an operations pre-plan, and disseminate the information to the involved parties.

Field Operations Analysis Techniques

Routine and repetitive construction operations are those comprised of cycles that can be optimized through traditional productivity analysis and improvement techniques. The techniques applied have developed over time, but are fundamentally based on time studies performed to record the time required to complete various tasks comprising a construction operation[2].

Field operations analysis was originally performed by observers using stopwatches and manually recording data. Oglesby et al.[3] noted several limitations to the technique including difficulties in determining exact start/stop points in a cycle, difficulties in observing multiple cycle components, and data being subject to the physical limitations and biases of the observer.

Time-lapse photography improved field operations analysis by providing all the information that makes such studies beneficial. Oglesby et al.[4] noted that time-lapse photography is able to record the interrelationships between observed resources and provides an easy to understand permanent record. Sprinkle[5] investigated its use and found a single camera is able to replace multiple observers and the resulting data can be repeatedly reviewed without doubt regarding is accuracy.

Video recordings replaced time-lapse photography due to the advantage of instant replay, continuous recordings, and less expensive and more reliable equipment[6]. Video recording has been used to document the construction of entire projects[7] and in field operations analysis[8]. While an improvement over photographic methods, the primary disadvantage of real-time recordings is the time required to review the data. Digital video has helped to overcome this shortfall and with the aid of software can be viewed at speeds up to 32 times real time. In practice it has been found that speeds greater than 4 times real time result in discontinuous or "jumpy" videos.

Observational techniques that rely on visual data are subject to two principle limitations: data is limited to that within the field of view of the observer or camera and the analyst must make instantaneous decisions regarding the start/stop of tasks based on visual information. On-board instrumentation systems have been employed to overcome these limitations[9,10]. Sensor data is recorded and analyzed through automated techniques to identify the timing of key points in a production cycle.

While each of the analysis techniques presented has been successfully employed, each is predicated on the availability of a field operation for observation and analysis. On-going operations are analyzed and improvements identified are implemented on the studied operation and subsequent operations.

Detailed Operations Pre-Planning

Unique and complex operations are, by definition, operations that have not been previously performed and do not present an opportunity for analysis and improvement through traditional techniques. A detailed and formal pre-planning process can be applied to develop an understanding of the operation and identify potential improvements. Oglesby et al.[11] notes that "pre-planning for on-site construction provides the thinking, arranges for the necessary elements, establishes the requirements, and develops the operating rules for all that happens at the work face."

Pre-planning is the process of giving advance thought to the details of the operation to be performed, anticipating interferences, shortages, and other hazards to successful performance. The resulting pre-plan documents the operational details of who, how, what, when, and where. Pre-plans typically take the form of cost estimates, schedules, task drawings, and physical or computer models.

Cost estimates are fundamental components of the pre-plan because cost is often the criterion for choosing between methods. The rigor of appropriate cost estimating also aid in developing the material, labor, and equipment requirements of the subject operation. Estimates prepared during pre-planning are invaluable when estimating the cost of changes to the work.

Schedules reflect plans and are thus a necessary component of pre-plans. Oglesby et al.[12] note that pre-planning without scheduling has little merit. Schedules indicate when work tasks are to be performed and depict the sequence in which tasks are to be completed. Schedules are also valuable in analyzing operational alternatives and time considerations are second only to cost.

Task drawings combine on a single sheet all the detailed information required by a field crew to perform the operation. Information typically includes a bill of materials, notes regarding any special considerations, and quantity summaries. The drawings only contain pertinent information and necessary dimensions, which are referenced in the same manner as it will be in the field.

Physical models are scale replicas of the project or component to be constructed. They are most beneficial for pre-planning erection and construction sequences. Models can be disassembled and used to plan fabrication sequence and material staging areas. Models may also be three-dimensional CAD models, which can be manipulated and viewed from any angle.

The fact that pre-planning benefits the project team and has value is not disputed. However, the value of it is difficult to quantify as the value is often in costs not realized. Ghio et al.[13] struggle to measure the value of operations pre-planning, but rather relies on comparing the outcome of a pre-planned project to one on which pre-planning was passed over. It is noted that the pre-planned project produced profits 80 percent greater than budgeted.

Laboratory Exercise

A laboratory exercise was designed to demonstrate the principles and value of operations pre-planning to students in an undergraduate construction means and methods course. The students were formed into groups of 4 students and each group constructed a replica of the Tower Bridge in London using the K'NEX Real Bridge Building Kit. Six of the groups constructed the bridge without any pre-planning, while the remaining six groups used the prior class session to pre-plan the unique and complex operations and constructed the bridge during the subsequent session. The pre-plans were formalized into a one-page written document submitted to the instructor at the beginning of the construction session.

The replica is shown in Figure 1 and consists of 10 components: 2 abutments, 2 towers, 4 cable and hanger assemblies, 2 bascule spans. Each component is assembled separately and then connected to complete the project.

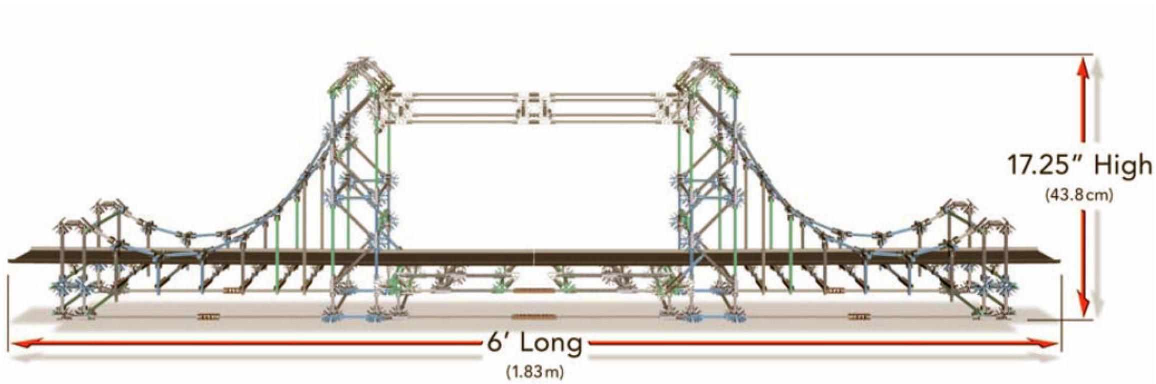

Figure 1: K'NEX Replica of the Tower Bridge[14]

Each group was provided instructions for constructing the bridge. The instructions were gray-scale photocopies of the color instructions provided in the K'NEX kit. As a result, the students were required to focus on the material requirements and connection methods, rather than simply assembling the parts. The instructions were similar to typical construction plans in that they provided overall views of the finished project and bridge components, a detailed parts list, and diagrams indicating how the components and individual pieces fit together. Figure 2 is a typical diagram for a bridge component.

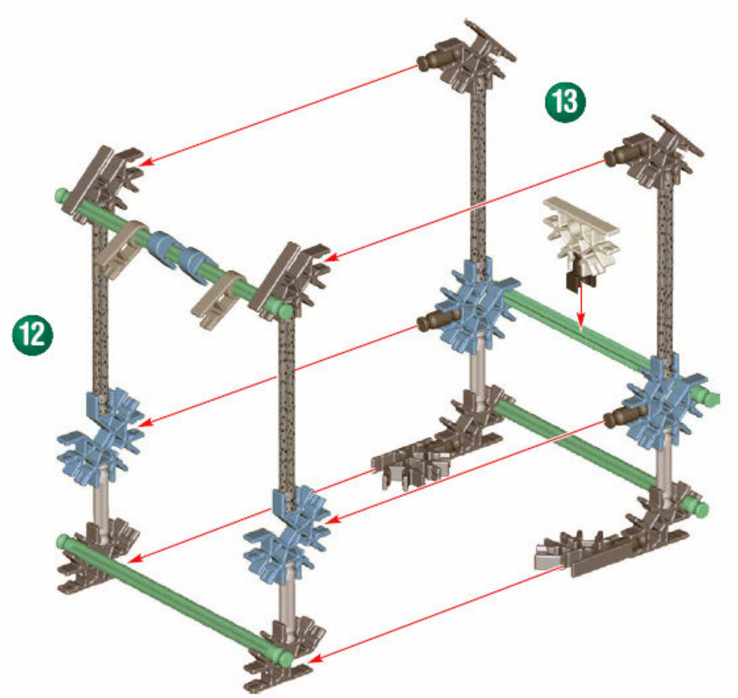

Figure 2: Typical Detailed K'NEX Instructional Diagram[15]

Materials were not provided at the construction site, but rather the K'NEX kit containing all the necessary parts was placed a short distance away. This required the groups to identify the necessary parts and transport the parts to the site. Not all parts contained in the kit were required for construction, which also caused the students to focus on the material requirements.

The pre-plans developed focused on methods of transporting and organizing the materials at the construction site, division of tasks among group members, sequence of construction for the components, and identifying the parts required for each component. Each of the groups that pre-planned the operations devised a method for separating the parts as they were retrieved from the kit and transporting them to the site. Most groups used small containers to transport and store the materials at the construction site. The manner in which groups divided the construction tasks varied, but generally the tasks were completed individually or by 2 teams of 2 members each. Each member or team was assigned the components for which they were responsible. The sequence of construction was generally provided by the instructions, but some groups planned the sequence such that teams completed connecting components at the same time. The instructions provided a summary of the parts required and some groups broke this summary down to the parts required for each component.

Figure 3: Construction of the Tower Bridge Replica

Results

A specific objective of the course was that students would be able to understand the principles of operations pre-planning and the results indicate that this objective was achieved. As part of a course objectives survey completed at the conclusion of the course, the students rated the degree of achievement at 4.83 out of a possible 5.00. This was the highest rating of any of the course objectives and a 5.00 rating indicates all students felt the objective was "completely" achieved.

The students enjoyed the exercise and performed the work with pride and enthusiasm. A friendly sense of competitiveness quickly grew between the groups. This resulted in an interest in the performance of each group. As part of a course review exercise, students were asked to list the one concept from the course that would stay with them the longest. The most frequently identified concept was of operations pre-planning and its value. The responses are summarized in Figure 4.

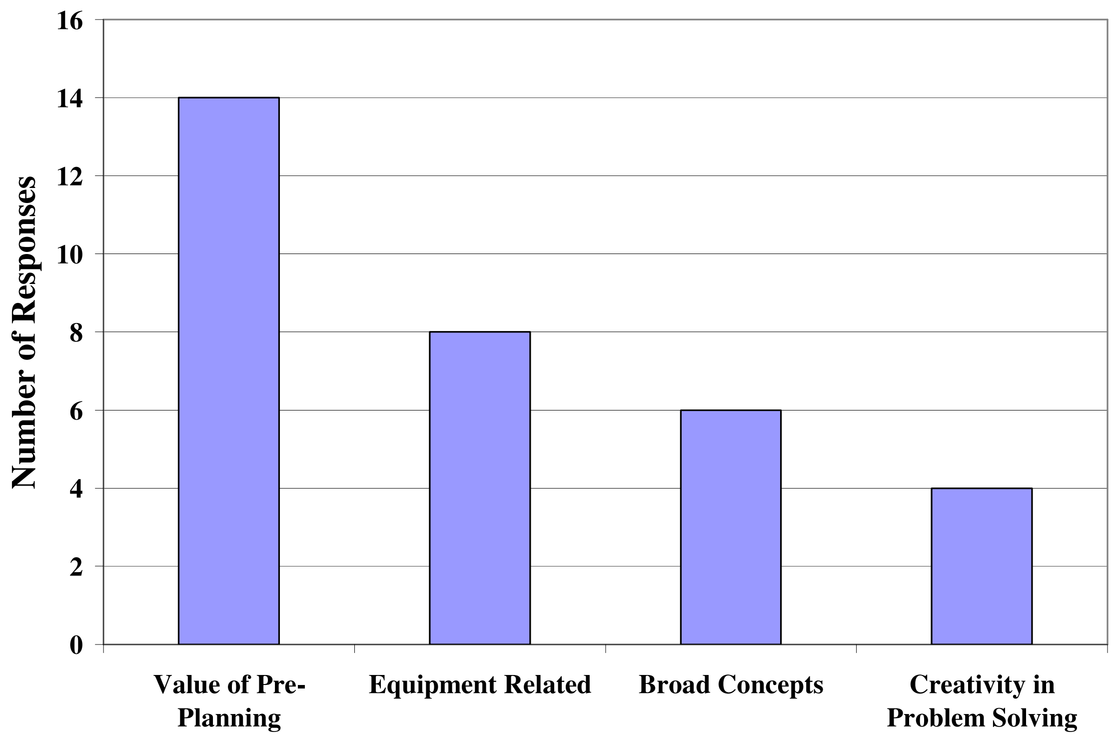

Figure 4: Student Responses Regarding Most Lasting Course Concept

The construction of each bridge was observed and time required for completion was recorded. Figure 5 summarizes the construction durations for both the groups that pre-planned their operations and those that did not. It is evident that pre-planning aids in the construction process and results in generally shorter construction durations, as the 3 shortest durations were achieved by groups that pre-planned and the 3 longest durations by groups that did not. The average construction time for groups that pre-planned was 62 minutes and for those that did not pre-plan the average time was 87 minutes. There is overlap in the duration data, but the 25 minute difference represents a nearly 30 percent decrease and is noteworthy.

It was observed that groups not performing pre-planning encountered a greater number of issues during construction. These issues generally resulted from a lack of understanding of the construction requirements and required either corrective re-work or discussion between group members to resolve. Some groups not pre-planning also reported confusion among the group regarding responsibility for specific bridge components and duplicate and unnecessary work.

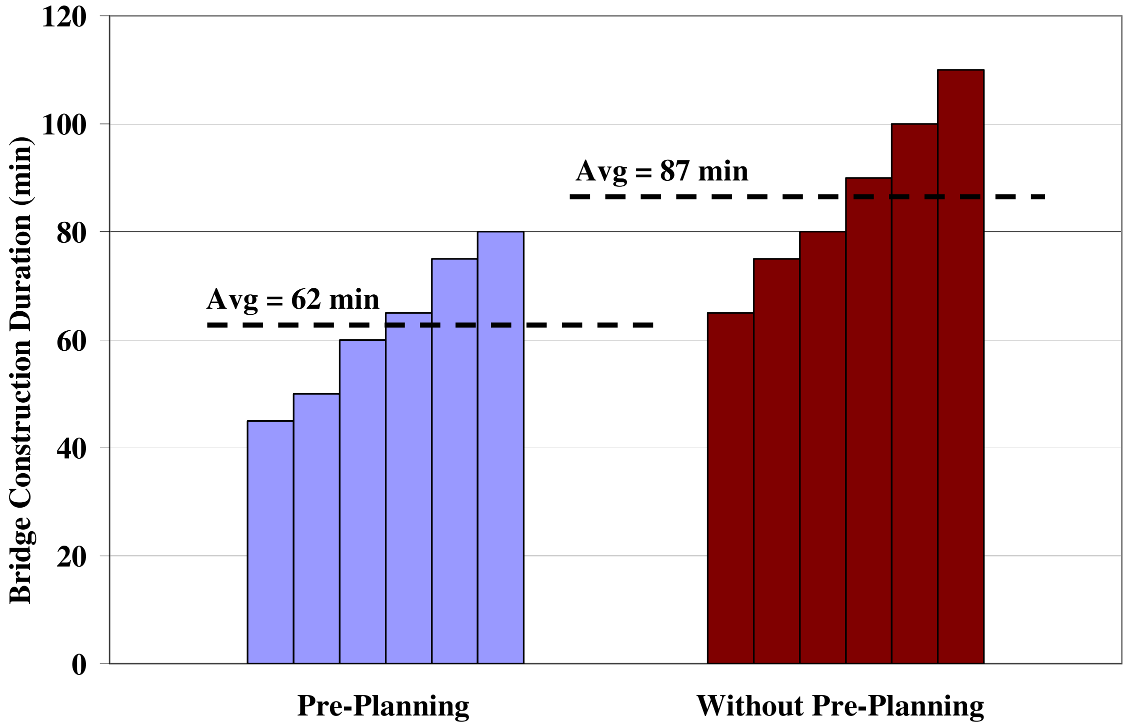

Figure 5: Effect of Pre-Planning on Construction Duration

Conclusions

The laboratory exercise using K'NEX to construct a replica of the Tower Bridge was successful in demonstrating the principles of detailed pre-planning for unique and complex construction operations. The exercise was well received by the students, who responded to a friendly competitive atmosphere and took pride in their performance. It was evident from observing the exercise that operations pre-planning improved the understanding of the construction requirements, reduced the amount of rework required, and reduced the time required for construction. The value of pre-planning was a concept the students took away from the course. This exercise will be incorporated into future construction means and methods courses conducted at Virginia Tech.

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1 Oglesby, C. H., H. W. Parker, and G. A. Howell, (1989), Productivity Improvement in Construction, McGraw Hill Companies, New York, NY.

[2] Ibid.

[3] Ibid.

[4] Ibid.

[5] Sprinkle, H. (1972), "Analysis of Time-Lapse Construction Films," *Journal of the Construction Division*, ASCE, 98(CO2), pp83-199.

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[10] Kannan, G. and M.C. Vorster (2000), "Development of an Experience Database for Truck Loading Operations," *Journal of Construction Engineering and Management*, ASCE, 165(3), pp201-209.

[11] Oglesby, C. H., H. W. Parker, and G. A. Howell, (1989), Productivity Improvement in Construction, McGraw Hill Companies, New York, NY.

[12] Ibid.

[13] Ghio, V. A., E. Valle, and L. Rischmoller (1997), "Preplanning: A Rewarding Experience," *Proceedings of the 5th Annual Conference of the International Group for Lean Construction*, IGLC, pp115-120.

[14] K'NEX Real Bridge Building Instructions (2003), K'NEX Industries, Inc., Hatfield, PA.

[15] Ibid.