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A Model For Collaborative Industrial Engineering Support and Performance Improvement of Construction Projects

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Abstract:

The Construction Industry is the largest industry in many countries (approximately US$4 trillion annually, worldwide, and over US$1trillion in the US). Despite modest improvements in erection methods most construction is still executed through time-honored but suboptimal techniques. Studies have indicated a loss rate of as much as 30% in the construction process due to errors, wasted time, and wasted resources. These costs of poor quality are passed on to society as inherent costs in the construction process. Although Frank Gilbreth, one of the "founding fathers" of Industrial Engineering did pioneer work on construction processes in the 1890's, the industry has not benefited from the contributions of industrial engineers to the extent experienced by the manufacturing and service sectors.

Through its Construction Division, the Institute of Industrial Engineers (IIE) has been promoting collaboration with the construction industry, and proposes to bring to it the type of improvement that Industrial Engineers (IEs) have contributed to other industries such as manufacturing, retail, and service industries. The Construction Division's mission involves harnessing the skills and knowledge of many Industrial Engineers (IEs) who work in the construction industry, or who have an interest in it. The purpose of this paper is to:

a) Communicate the methodologies proposed by IEs to support the construction industry and to enhance its performance
b) Provide brief examples of IE-based improvements

Keywords: Performance Improvement, Lean construction, Systems Integration, Supply Chain, Quality management.

1.0 The State of the Construction Industry

Despite a value of more than 1.2 Trillion U.S. dollars in 2006 and an employment of over 7.4 million people, the U.S. Construction Industry has not had the benefit of much attention from industrial engineers. The U.S. Department of Labor's Bureau of Labor Statistics (BLS), reported construction activity in that period as approximately 8.0% of the Gross Domestic Product. Estimates of construction productivity levels are elusive – the Bureau of Labor Statistics does not track productivity levels consistently. The U.S. Department of Commerce, reported that between 1990 and 2000 productivity rose by approximately only 0.8 percent compared to more than 2 percent for all US industries. In recent years construction costs have been increasing at the same time; raw materials such as steel and cement have been rising, especially as a result of large worldwide demand. Labor costs are a major component of most construction projects – in the vicinity of 40 percent, yet on many construction sites a large percentage of the daily labor hours are unproductive. As other industries such as service and manufacturing have reached higher levels of quality and performance, the majority of construction work is still based on comparatively inefficient time-honored procedures and methods.

This paper describes briefly how the tools and techniques long used by industrial engineers in the manufacturing industry can enhance construction quality, productivity, customer satisfaction, and profitability. It also explains how industrial engineers can be positioned in the construction industry to serve as systems integrators both in traditional (non-lean) environments as well as in those projects where the stakeholders are committed to lean methods.

2.0 Background on the Industrial Engineering Field

The Institute of Industrial Engineers defines an Industrial Engineer (IE) as: "one who is concerned with the design, installation, and improvement of integrated systems of people, materials, information, equipment and energy by drawing upon specialized knowledge and skills in the mathematical, physical and social sciences, together with the principles and methods of engineering analysis and design to specify, predict and evaluate the results to be obtained from such systems. In addition to classical methods such as work sampling, methods engineering and time studies, IE involves mathematical process modeling, management science methods and ergonomics as well as automation and robotics.

IEs have been involved in virtually every other type of enterprise, with outstanding results – the earliest contributions were in the manufacturing arena and later on in the service sector. IEs have enabled the fast food industry to produce consistent quality at high volumes. The health care industry has also used IEs to enhance quality and reduce errors in service delivery. Package delivery organizations owe much of their competitive edge to the efforts of IEs.

Frank Gilbreth who was a pioneer of Industrial Engineering did one of the earliest IE studies in the field of construction. Around 1895 he became a bricklayer and noticed inconsistencies in the procedures used by the person assigned to teach him the process. Gilbreth went on to study bricklaying from an analytical perspective and identified the "best method" for doing this work in order to make workers as productive as possible, with minimal fatigue. Unfortunately, the industry did not continue this approach. To this day, except for a few innovations such as tilt-up panels and pre-manufactured components, construction crafts still work much like their predecessors did.

2.0 Industrial engineering traits and the construction industry

IEs have a solid foundation in engineering principles, and very importantly, are highly oriented to the interaction between people and the work environment. Design and construction projects can only be successful when all the parties work together harmoniously, and it is quite a challenge to orchestrate these complex activities as construction, by its very nature, is adversarial. Trained as systems integrators, IEs can provide strategies for having the involved parties work together for maximum effectiveness.

IEs are actively involved with improving quality and performance overall in products and services. They have routinely practiced the concepts of quality management established by such luminaries as Deming, Juran, Feigenbaum and Crosby that are embodied in the Malcolm Baldrige National Quality Award. Lean and Six Sigma are examples of systematic approaches to performance improvement in which IEs have been playing a leadership role.

3.0 Tools and techniques for construction improvement:

There are several areas in the construction industry where industrial engineering techniques and approaches may be applied. There are many examples of the use of these methods in the service and manufacturing industries. Some of the tools and techniques are as follows:

Ergonomics/Human factors	Value Engineering
Work measurement	The Learning Curve
Quality Management	Productivity Management
Continuous Improvement	ISO 9000
Cycle Time Analysis	Lean Methods
Supply Chain Management	Automation/ Robotics
Radio Frequency Identification (RFID)	Safety Management
Systems Integration	Simulation
Quality Function Deployment	Facilities Layout
Operations research	

4.0 Examples of/ opportunities for IE applications:

Activity sampling studies have shown that the working portion of activities generally occupies 40 to 60 percent, and by the same token over 40 percent of labor hours tend to be unproductive. There are many reasons for lost time – poor communications, waiting on assignments, waiting on resources, double material handling, rework, accidents, late or inaccurate job status reports, lack of supervision, etc. One third of these losses reflect issues that are within management's control. Construction profitability is directly linked to labor productivity. Industry-wide studies indicate that most construction projects yield net profits of two to three percent of the total project cost.

A hypothetical example:

Contract price =	$20,000,000
Labor cost (40%) =	$8,000,000
Other costs, overheads, etc=	$11,400,000
Net profit =	$600,000

Assuming a five percent reduction in labor cost due to productivity improvement.
Savings in labor cost = $8,000,000 x .05 = $400,000

Revised net profit = $600,000 + $400,000 = $1,000,000.
Hence, a five percent improvement in labor productivity can improve profitability by 66.7 percent.

4.1 Lean Methods

Lean construction is accomplished through the application of lean theory, principles and techniques, with production management techniques to make significant improvements particularly on complex, uncertain, and quick projects. Industrial engineers have accomplished these approaches in the manufacturing environment for decades and are well positioned to help a committed team of stakeholders to apply them to the construction environment. Five lean principles are essential (Womack and Jones 1996):

1. Value: identify the value of the project, the customer's needs, and the agents involved in all stages from inception to the delivery process,
2. Value stream: The construction process is improved by mapping the whole value stream, establishing cooperation between the agents or participants, and identifying and eliminating wasteful activities.
3. Flow: Business flow: related with the information of the project (specifications, contracts, plans, etc.)
   Job site flow: Construction activities and the way they have to be done.
   Supply flow: The flow of materials involved in the project. (Supply chain).
4. Pull: Work is released to the downstream participants only as demanded by their output requirements.
5. Perfection: develop work instructions and procedures, and establish quality controls.

IE applications in modular homebuilding: A study conducted by the Housing Constructability Lab (HCL) at the University of Central Florida, USA, identified significant savings in labor costs and operational costs, resulting in larger profit margins (Elshenawy et. al., 2002). HCL researchers worked with one of New England's largest modular builders in an effort to improve their on-site modular finish process. Using findings from a kaizen rapid improvement event held in 2001, the builder has improved both the operation and the quality of their homes:

- Labor productivity improved by 59% - through a combination of improvements in the factory and better construction site supervision
- Cycle time reduced by 22% - through tighter scheduling
- Building envelope tightened to 5 ACH50 * through the combined use of gaskets and foam around the marriage line

As part of this exercise, an enhanced single-home finishing schedule was developed. It showed that the cycle could be further reduced, from an average of 72 days to less than 30 days.

Small-scale contracting operations can benefit greatly from IE applications. Attah (2006) reported the results of small contractor roadwork activities in Dallas, Texas, based on public sector projects awarded to the lowest bidder. Through the application of methods analysis, ergonomics and concurrent engineering the following savings were derived:

- Eighty percent reduction in number of unplanned events.
- Ninety-five percent reduction in complaints – e.g. from city, property owners, traveling public, and utility companies.
- Zero fines from regulatory bodies such as EPA and OSHA.
- Thirty percent reduction in typical Public Works Construction project cycle time.
- Twenty percent greater weekly productivity, 15% shorter project duration
- Reduced typical equipment rental cost by 15%.
- Eliminated damage to freshly paved surfaces.
- Achieved 90% cost reduction in rework operations.

4.2 Sustainable construction

Construction waste also puts additional pressure on the environmental sustainability of housing. For example, 36.4% of total US primary energy consumption comes from construction. It also accounts for36% of total US CO_2 emissions, 30% of total US global warming gases such as Methane, Nitric Oxide, and Hydro Fluorocarbons, and 60% of total US ozone depleting substances. Construction waste is a major problem; each residential building accounts for 3-7 tons of waste. Nationally, the US produces 136 million tons of construction waste, but only 20% to 30% of this is recycled or reused. IE's can do much to reduce waste, optimizing material purchases and developing construction practices that increase the recycling of material waste.

5.0 Description of the collaborative model

This model in Figure 1 identifies the parties to a construction project as a "Construction Delivery Team". Although they have separate contractual relationships with each other, the model requires that they work toward common goal and share information that will support goal attainment. The industrial engineer is indicated in the role of "Project Industrial Engineer" providing support to the team. The vertical box at the left of the diagram indicates the components of the IE support; the primary support is that of quality and performance improvement. The components include continuous improvement management, systems integration, quality and productivity improvement, lean methods management, Six Sigma management, performance measurement and benchmarking, safety management and post occupancy evaluation (POE).
The industrial engineering function interacts with various parties in the design and construction cycle on an ongoing basis as projects are conceived, designed and constructed. It also promotes systems integration in which information, human and material resources come together to form an effective construction process/system. This would be especially beneficial on large projects involving new facilities, as the potential for savings is enhanced as the size and scope of the project increase. In such cases the systems and process improvements and waste reduction provided by the industrial engineering function would far more than cost-justify the cost of the salaries involved.

Other activities that are not shown but that may be added to the model include: sustainable design and construction support, Value Engineering, innovation/automation support, and training. Because of his/her flexibility, the IE may be included in these activities based on the need of a particular project

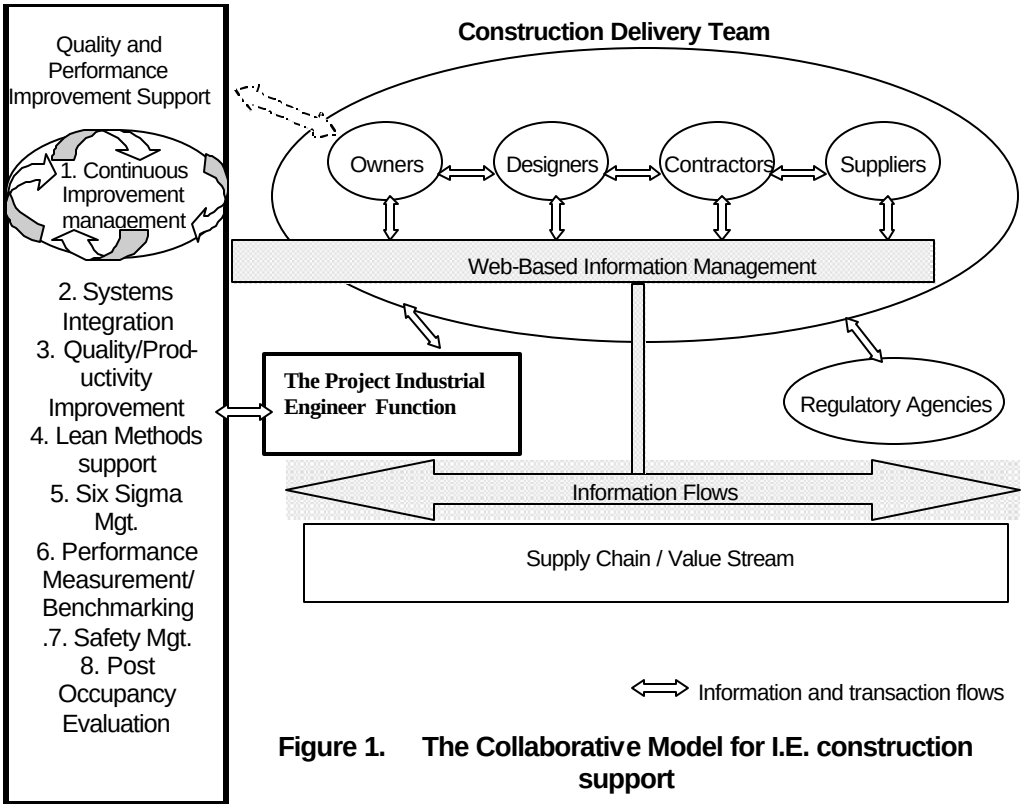

Figure 1. The Collaborative Model for I.E. construction support

The following project stages would especially benefit from IE support.
a) Site selection. IEs have a number of optimization techniques available for selecting locations that make a new facility best able to serve its customers, both external and internal. Quantified comparisons are made between initial cost, operating cost, and other owners' criteria for a variety of alternative locations in order to make the best possible selection.

b) Facilities Design. Facilities Design is a core activity of industrial engineering. Facilities design methodology and applications are available not only for manufacturing, but for service operations as well. While architects and other design professionals address the aesthetic and special needs of a facility, the IE provides support through optimal and heuristic solution approaches. Risk-averse approaches quantify and compensate for changing future needs.

c) Value engineering and Constructability Reviews. The industrial engineer's multi-disciplined approach is well suited to driving and facilitating the VE process. The I.E. can be especially valuable in facilitating a multidisciplinary group of design and construction professionals in brainstorming, generating ideas, and in conducting life cycle analysis for the comparison of alternatives. IEs can improve constructability reviews by contributing design for manufacturability techniques that are typically used in industry.

d) Construction site logistics. IE techniques can be used to optimize the use of each construction site, thereby improving productivity and profitability. There are many variables in the construction environment such as geographic location, weather conditions, and the type and configuration of the materials and equipment and materials involved. An example of a typical site problem is how to position tower cranes for moving materials in the optimal manner. The crane boom needs to swing through a given angle at a particular velocity, and the trolley must travel along the boom for a given distance. Operations research techniques can be used to solve these problems.

e) Construction performance improvement. Productivity /quality improvement initiatives involve the application of the continuous improvement or PDSA (Plan Do Study Act) cycle promoted by quality gurus such as Deming, Shewhart, and Juran. This cycle involves dedicated measurement of performance, followed by process improvements that are verified through further measurement. While this activity is a staple of the IE profession, construction professionals are far too focused on ensuring that subcontractors "get the work done" to give this endeavor the attention it deserves. IEs can investigate best practices and determine exemplar rates for the execution of various construction tasks. The exemplar rates, in turn, can be used to calculate PAR (performance ability ratio) values that indicate the activities that benefit most from performance improvement efforts.

f) Systems integration. A major criticism of the construction industry is that it has become extremely fragmented, with all the parties acting in their own self-interest. The concepts of supply chain management and lean construction require close collaboration between the parties; hence there are significant benefits to be derived by systems integration. Effective communication is a critical prerequisite for a successful project but is inhibited by geographic dispersion, response times, document revision control, and cost control. Industrial engineers can help to overcome the barriers to this process.

6.0 Conclusions and Recommendations

In summary, industrial engineers can have a major impact on construction quality, productivity and profitability by helping management to improve its decision-making and the logistics of the labor force. While construction professionals ensure that work schedules are properly planned and executed, the IE can support their efforts by finding ways to make them more effective. The IE can help the parties to construction to accomplish more as a team by assisting with systems integration so that there is more emphasis on a common goal than on the self-interest that accompanies most projects. Further gains can be derived by addressing other construction processes and supply chain management issues. On larger projects, an IE could be a part of the team, as are civil, electrical and mechanical engineers. To accomplish this future state, the following recommendations are offered:

- Construction professionals should encourage collaboration between construction professionals and IEs
- IEs should maintain productivity indices and link them to the organization's profitability
- IEs should evaluate the benefits of new technology, such as automation and promote them to construction organizations' leadership team
- IEs should promote quality systems such as Six Sigma or ISO 9000 and demonstrate their impact on profitability

•IEs should influence organizations to include safety as a VALUE, so it becomes an expected behavior

REFERENCES

Acharya, P., Pfrommer, C., and Zirbel, C., (1995) "Think Value Engineering", *Journal of Management in Engineering* Nov/Dec, pp 13-17.

Adrian, J,, Adrian, D., (1995), "*Total Productivity and Quality Management in Construction*" Stipes Publishing, LLC, Champaign, IL 61820

Attah, A., (2006), "Systems Integration Approach for Optimizing Construction Performance", Abstract 76, Industry Solutions Conference, Institute of Industrial Engineers, May 20-24. Orlando, FL., U.S.A.

Burati, J.L., Jr., and Oswald, T. H., (1993), "Implementing TQM in Engineering and Construction", *Journal of Management in Engineering*, ASCE, New York, USA, Vol. 9, No. 4, pp. 456-470.

Davis, R., (1999), "Creating High Performance Project Teams", *Proceedings, Construction Industry Institute Conference*, Austin, Texas. Sep 26-28..

Elshennawy, A.K., Mullens, M., and Nahmens, I., (2002), " Quality Improvement in the Modular Housing Industry, *Industrial Engineering Research '02 Conference Proceedings*, Orlando, FL., U.S.A.

Forbes, L., (1999), "*An Engineering-Management- Based investigation of Owner Satisfaction, Quality and Performance Variables in Health Care Facilities Construction*", Dissertation, University of Miami

Goetsch, D.; Davis, S.; (2006), *"Quality Management: Introduction to Total Quality Management for Production, Processing, and Services"*, Prentice Hall, Fifth Edition.

Grifffis, F.H., Farr, John V., Morris, M. D., (2000), "*Construction Planning for Engineers*" McGraw-Hill

Marans, R. W. and Spreckelmeyer, K. F., (1982), "Measuring Overall Architectural Quality: A component of Building Evaluation," *Environment and Behavior*, 14 (6), 652-670.

Obrien, W., London, K., and Vrijhoef, R. (2002) "Construction supply chain modeling: A research review and interdisciplinary research agenda". Proceedings *10th International Group for Lean Construction Conference*, August, 2002, Gramado, Brazil

Oglesby, C., Parker, H. W., & Howell, G.A., 1989, " *Productivity Improvement in Construction*" McGraw Hill Inc.