Measuring and Improving the Productivity of the U.S. Construction Industry: Issues, Challenges, and Opportunities

Robert E. Chapman and David T. Butry
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

Abstract

Although the construction industry is a major component of the U.S. economy, it has experienced a prolonged period of decline in productivity. Due to the critical lack of measurement methods, however, the magnitude of the productivity problem in the construction industry is largely unknown. To address these deficiencies, efforts are underway that focus on the measurement of construction productivity at three levels: task, project, and industry. This white paper discusses how such measures can be developed, how they are related to the use of information and automation technologies and construction processes over the life of the project, and how to build on several ongoing collaborative efforts aimed at improving the efficiency, competitiveness, and innovation of the construction industry. The paper concludes with a discussion of the role that the summer 2008 National Academies Workshop can play in bringing together key construction industry stakeholders to identify and prioritize activities that have the greatest potential for improving the productivity of the U.S. construction industry over the next 20 years.

1 Construction: An Engine for Economic Growth

Construction is an engine of growth for the U.S. economy. Investment in plant and facilities, in the form of construction activity, provides the basis for the production of products and the delivery of services. Investment in infrastructure promotes the smooth flow of goods and services and the movement of individuals. Investment in housing accommodates new households and allows existing households to expand or improve their housing. It is clear that construction activities affect nearly every aspect of the U.S. economy and that the industry is vital to the continued growth of the U.S. economy.

In 2006, the latest year for which construction data are available, the construction industry's contribution to gross domestic product (GDP) was $648 billion, or 4.9 % of GDP.[1] In 2006, the value of construction put in place was $1 192 billion ($873 billion for new construction, $319 billion for renovation).[2] Maintenance and repair added another $157 billion.[3] Approximately 30 % of the value of construction put in place—$368 billion—was due to the demand for manufactured products, materials, components, and systems.[4] Constructed facilities increase the demand for manufactured goods once they go into use. For example, $156 billion was spent on contents and furnishings in 2006.[5] Consequently, the construction industry generated over $500 billion in demand for manufactured products in 2006. Once constructed facilities go into use, they generate demands for energy, water, and services. In 2006, these demands amounted to $686 billion, of which $572 billion was for energy.[6]

Construction also has a major impact on U.S. employment. In 2006, 11.7 million persons were employed in the construction industry.[7] This translates into 8.1 % of the total U.S. workforce. The composition of the construction workforce differs from much of the U.S. workforce due to the large number of self-employed workers (sole proprietorships and partnerships). Within the construction industry, there are 1.8 million self-employed workers. In contrast, manufacturing, which employs 16.4 million workers, has only 330 thousand self-employed workers.[8] The large number of self-employed workers both reduces the size of the average firm and increases fragmentation within the construction industry. Both factors complicate the adoption of new technologies and practices. Construction employment is affected by both the weather and the business cycle. Thus, year-to-year changes in employment can be substantial, resulting in layoffs and hiring surges. The cyclical nature of construction employment produces shortages in many highly-skilled trades. These shortages adversely impact productivity in the construction industry. Finally, declining construction productivity is exacerbated by the influx of unskilled labor from abroad, many of whom find their first employment opportunity in the construction industry.

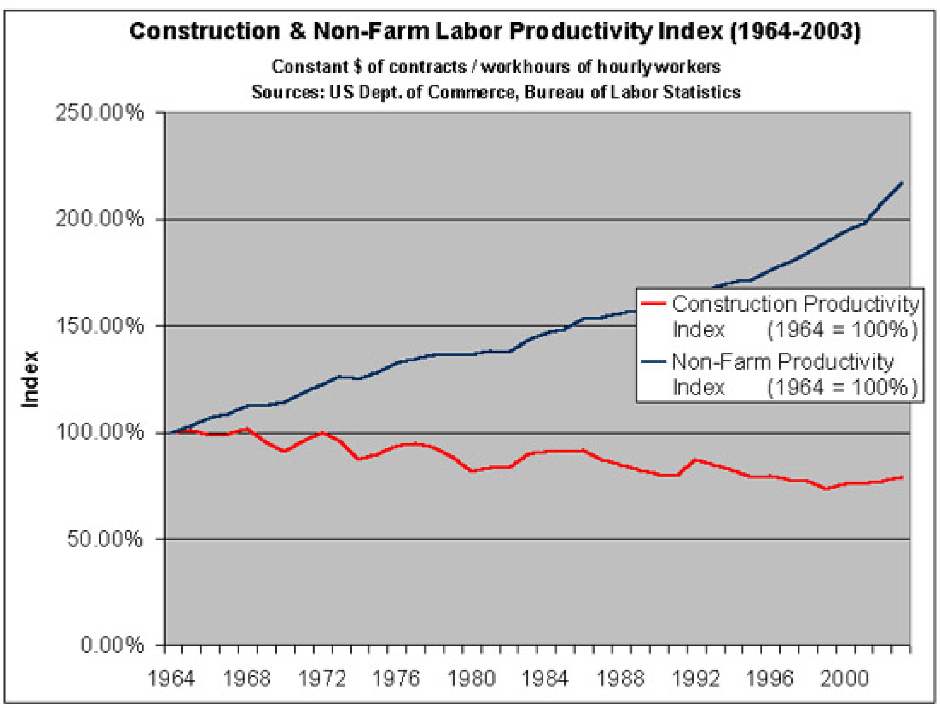
2 Productivity and Competitiveness

Given the demonstrated large impact of construction on the nation's macroeconomic objectives, effective construction research becomes critical to the economy. Key drivers for change in construction research are sustainability and environmental security; competition due to globalization and offshoring; homeland security and disaster resilience; infrastructure renewal; demand for better, faster, and less costly construction; and information technology.

The problem is that the American construction industry invests little in research relative to its significant GDP contribution to the economy. A landmark study co-sponsored by the Civil Engineering Research Foundation (CERF) and the National Science Foundation (NSF) involved a nationwide survey of civil engineering-related research and development (R&D). The study, later published by CERF,[9] is especially noteworthy because it includes R&D associated with each of the key construction industry stakeholders. The CERF study reported that all key construction industry stakeholders combined invested in R&D at a rate that corresponds to only 0.5 % of the value of construction put in place. This translates into approximately $5.5 billion in 2006. A recently published NSF study covering companies performing industrial R&D provides a useful contrast.[10] Private sector R&D investments in manufacturing totaled nearly $143 billion in 2005. Total R&D investments in construction were even surpassed by segments of the manufacturing industry (e.g., $8.4 billion for machinery, a mature segment of the industry). Underinvesting reduces the potential for research-inspired innovations that contribute to substantial national benefits—namely constructed facilities that are more user and environmentally friendly, affordable, productive, and that are easier, faster, and more life-cycle cost effective to build, operate, and maintain. Given the impact of construction spending on the economy's health, and that construction research helps make construction workers more productive and the construction industry more globally competitive and profitable, construction research becomes a critical variable in generating economic growth.

A recent article by Paul Teicholz highlights the magnitude of the construction industry's perceived decline in productivity (see Figure 1).[11] As measured by constant contract dollars of new construction work per field work hour, labor productivity in the construction industry has trended downward over the past 40 years at an average compound rate of -0.6 % per year. That is, construction projects have required significantly more field work hours per constant dollar of contract. This is particularly alarming when compared to the increasing labor productivity in all non-farm industries, which has trended upward at an average compound rate of 1.8 % per year. In other words, the construction industry seriously lags other industries in developing labor saving ideas and in finding ways to substitute equipment for labor. Teicholz reiterates the points noted earlier for their adverse impact on construction labor productivity, namely the lack of R&D spending, fragmentation within the industry, and declining real wage rates. He also notes that despite the fact that there has been a significant adoption of new information technology by the construction industry over the past 35 years, these applications tend to run in a stand-alone mode that does not permit improved collaboration by the project team.

Figure 1 Labor Productivity Index for the U.S. Construction Industry and all Non-farm Industries



Source: Teicholz, Paul. "Labor Productivity Declines in the Construction Industry: Causes and Remedies." *AECbytes Viewpoint*. Issue 4. April 14, 2004.

It should be noted that not everyone in the construction industry agrees with Teicholz's assessment. For example, Young and Bernstein, in their McGraw Hill *SmartMarket Report*,[12] contend that the U.S. construction industry is making productivity improvements through innovation with new technologies, processes, and services. Teicholz asserts, however, that a fragmented market with very small players makes application of these innovations less frequent than desired for a healthy increase in industry productivity. Another reason the Teicholz chart may show declining productivity is that it focuses on field work. For example, many of the improvements in construction productivity in the oil and gas industries over the past decade stem from the use of offsite fabrication facilities, where component production is well-controlled and highly-automated.[13]

The debate about the perceived decline in construction productivity highlights both the measurement challenges and the factors that affect construction productivity. For example, Allen argues that construction productivity declined between 1968 and 1978 and that the biggest factor in the decline was the shift in the mix of output from large-scale commercial and industrial projects to residential construction and its associated lesser skill requirements.[14] Stokes also argues that construction productivity declined between 1968 and 1978 and asserts that the major contributing factor to that decline was slower growth in capital per worker.[15] This is in sharp contrast to findings from a study by Goodrum and Haas that examined productivity measures for 200 construction activities over a 22-year period.[16] Goodrum and Haas found that activities that experienced a significant change in equipment technology (i.e., hand tools and machinery) also witnessed substantially greater long-term productivity improvements. Faruqui *et al*. examined productivity growth for selected business sectors between 1987 and 2000.[17] During the 1987 to 1996 period, construction experienced a slight increase in productivity, whereas between 1996 and 2000, construction experienced a sharp decline in productivity. Even during the 1987 to 1996 growth period, construction productivity improvements significantly lagged productivity improvements in manufacturing, services, and primary industries (i.e., agriculture, fishing, mining, and forestry). Other industry studies have identified inefficiencies ranging from 25 % to 50 % in current methods for coordinating labor and managing, moving, and installing construction materials.[18]

The debate about whether construction productivity is declining, holding its own, or increasing can not be easily resolved, because there are no industry-level measures of productivity for either the construction industry as a whole or its components (i.e., commercial, industrial, public works, and residential). Such measures do exist for manufacturing, and they are routinely disseminated by the Bureau of Labor Statistics (BLS).

3 Measurement of Construction Productivity: Task, Project, Industry

The nature of the construction process points to a need for measures of construction productivity at three levels: (1) task; (2) project; and (3) industry. ***Tasks*** refer to specific construction activities such as concrete placement or structural steel erection. ***Projects*** are the collection of tasks required for the construction of a new facility (e.g., the construction of a new commercial office building) or renovation (i.e., additions, alterations, and major replacements) of an existing constructed facility. ***Industry*** measures are based on the North American Industrial Classification System (NAICS) codes for the construction sector and would represent the total portfolio of projects.

Producing measures of construction productivity at each level involves the development of both metrics (i.e., the definition of the appropriate measure [parameter] that forms the basis for the calculation) and tools (i.e., the means through which construction industry stakeholders can perform the calculation for the selected metrics). Once produced, these metrics and tools will help construction industry stakeholders make more cost-effective investments in productivity enhancing technologies and life-cycle construction processes; they will also provide stakeholders with new measurement and evaluation capabilities (e.g., enabling them to simulate key elements of the project delivery process).[19]

Leading industry groups, such as the Construction Industry Institute (CII),[20] Construction Users Roundtable (CURT), and FIATECH,[21] have identified the critical need for fully integrating and automating life-cycle construction processes. Having metrics and tools will address that need and enable those industry groups and other stakeholders to: (1) determine construction productivity at both discrete and aggregate levels; (2) evaluate the performance of promising automation and integration technologies; and (3) measure the value of real-time monitoring and control of construction processes.

The development of metrics and tools is complicated because each measurement level (i.e., task, project, and industry) has different analysis requirements. The development of metrics is further complicated by the fact that there are currently no published project-level construction productivity metrics. As noted earlier, there are no industry-level measures of productivity for the construction industry. Thus, the challenge is to develop metrics and tools for application in an industry where the measurement science for achieving breakthrough improvements in productivity is critically lacking.[22]

The basic concept underlying construction industry productivity measures is a comparison of the output of a task, project, or industry with the corresponding factors of production (inputs) required to generate that output.[23] The output and inputs of production thus constitute the basic components of every productivity measure. Typically, productivity measures are formulated as a ratio of output to one or more inputs. If only one of the inputs is used, then the ratio is a single factor productivity measure. A common example of this type of measure is output per labor hour. If all of the inputs are used, then the ratio is a multifactor productivity measure.

3.1 Task

Task level metrics are widely used within the construction industry. Most task level metrics are single factor measures and focus on labor productivity. For example, R.S. Means has published task level metrics for many years.[24] Typical task level metrics published by R.S. Means estimate how much of a given output is produced by a designated crew in a normal 8-hour day. In this case, the denominator is the number of hours associated with a designated "crew day." Thus, for a designated crew day, higher output is better. In this case, higher output equates to higher task labor productivity.

The CII Benchmarking and Metrics Program uses a different metric to measure task labor productivity. CII fixes the output (e.g., cubic yards of concrete put in place) and measures the labor hours required to produce that output.[25] In this case, the denominator is the fixed output and the numerator is the number of labor hours. Thus, for a given amount of output lower labor hours is better. In this case, lower labor hours equates to higher task labor productivity.

Both the R.S. Means and the CII task labor productivity metrics include explicit measures of output and labor hours in the values reported. Such metrics are easy to understand and are widely used within the industry as a basic estimating tool. To differentiate these metrics from alternative formulations, we use the term "raw metrics" to refer to these ratios of input and output. These metrics are raw in the sense that they include the units of measure and are based on unadjusted outputs and labor hours. For example, the relative prices for selected labor inputs and the given output may vary over time. There can be many reasons for such changes (e.g., expanded use of information and automation technologies, use of equipment with increased functionality, and changes in construction processes). These factors and a number of others are discussed in Section 4 of this white paper.

The CII Benchmarking and Metrics Program collects data on a project basis, where productivity is but one data element. The raw task level metrics produced by CII include not only the average productivity for that task—referred to as a baseline measure—but the full set of observed values. The observed raw task productivity values are then rank ordered into a distribution. Once this is done, the raw task productivity values can be assembled into quartiles. CII researchers can then examine the characteristics for a given task associated with projects in the best performing quartile and in the worst performing quartile. This topic is explored further in Section 5.1 of this white paper.

A task productivity index is an alternative to the raw metrics discussed previously. An index is a dimensionless number, pegged to a reference data set, where the reference data set establishes the baseline value for one or more components of the index. An index can be a ratio of raw metrics. For example, the denominator could correspond to the baseline value for that task's labor productivity (e.g., labor hours per cubic yard of concrete) and the numerator could be the value for a specific project. In that case, the computed value of the index shows how that project's task productivity compares to the overall average of the reference data set. Alternatively, the numerator could correspond to an average value for a new data set of task productivity values collected at some future point in time. Thus, the index can be used to track how task productivity is changing over time.

An index can also incorporate additional information, such as the value of a deflator to help control for changes in relative prices over time. Because the index is a dimensionless number, users can focus on the changes in the index value rather than the functional form of the metric underlying the index. If for example, the index value was pegged at 100.0 at time zero and higher values are better, then a future value of 102.5 indicates improvement in the amount of 2.5 %.

3.2 Project

Project level metrics are more complicated because a project is a collection of tasks. The inputs and outputs for a given task, say concrete placement, differ from those of another task, say structural steel erection. Thus, it is not possible to aggregate the individual raw task productivity metrics into a project productivity metric unless adjustments are made.

One way to make these adjustments is to use a reference data set to calculate baseline values for each task, in the same way as described Section 3.1. Information is still needed, however, to calculate a meaningful project level productivity metric. For instance, information yielding the task weight (share that it represents to the overall project) is required, as is an understanding of the task flows. Because some tasks are completed in parallel, while other in series, the composition of the task flows affects overall project productivity. Therefore, each component of the project productivity metric contains: (1) the task weight; (2) the raw task productivity baseline value in the denominator; (3) the raw task productivity value for that project in the numerator; and (4) a measure of the task mix (in parallel versus in series task flows). The project productivity index value is a function of the individual components.

The project level productivity metric just described is useful in measuring how an individual project compares to the overall average in the reference data set. In addition, data from all projects can be compiled into a distribution. Further analyses can then be conducted to identify characteristics associated with the best performing or worst performing projects, a topic taken up in Section 5.1 of this white paper.

A project level productivity index can also be used to track changes in project productivity over time. In this case, the reference data set corresponds to time zero. For each index component, the values for the task weights and the task baseline values appearing in the denominator are equal to values computed in the reference data set. The numerator in each index component then becomes the average value of the corresponding task productivity in the future data set. As noted earlier, an index can also include a deflator to adjust for changes in relative prices over time.

A variant of Teicholz's formulation shown in Figure 1 can be used to produce an alternative project level productivity index. In this case, the index is the quotient of two ratios, in each ratio the numerator is the value of construction put in place and the denominator is the number of field work hours. As noted earlier, a reference data set can be used to fix a baseline value for the ratio of value put in place to field work hours. The baseline value for the ratio is then used as the denominator in the index calculation. How an individual project compares to the baseline is determined by inserting its ratio of value put in place to field work hours in the numerator of the index. Alternatively, this project level productivity index can be used to track changes in productivity over time by following the process described in the previous paragraph.

3.3 Industry

At the industry level, productivity—the amount (or value) of output produced per unit of input—provides a measure of industrial efficiency. The Bureau of Labor Statistics (BLS) publishes two common measures of productivity: (single factor) labor productivity and multifactor productivity.[26] BLS measures labor productivity as the ratio of the value of output produced for sale to labor hours worked. In the case of an industry producing multiple outputs, a Törnqvist index (weighted sum of the natural log of the ratio of output in different time periods) is used to chain multiple output indices together to form a single output measure.[27]

Because the value of output is influenced by other forces exogenous to labor, such as changes in technology, multifactor productivity measures provide a useful indicator of industrial productivity. BLS measures multifactor productivity using output, labor, capital, and intermediate purchases input. A Törnqvist index is used to combine the inputs into a single measure of production.[28] While multifactor productivity may be viewed as a better measure of productivity (compared to a single factor, labor productivity measure), it is obviously more costly in terms of data required.

The BLS does not collect nor report productivity measures for the construction industry. This appears to be due to the lack of suitable data.[29] Some have argued that measuring construction industry productivity is challenging due to a large number of small firms operating on a minimal profit margin, and to the industry fragmentation.[30] The BLS maintains productivity measures for other industries with seemingly similar attributes (e.g., full-service restaurants [NAICS code: 7221]; drinking places [NAICS code: 7224]; automotive repair and maintenance [NAICS code: 8111]). The BLS Current Employment Statistics (CES) survey provides statistics on annual labor hours by industrial classification. Labor statistics are available for the construction industry, so presumably the lack of data pertains to output (and capital and intermediate purchases inputs for multifactor analysis) and deflators.

Two sources of data are currently available that measure the value produced by the construction industry: U.S. Census Bureau's Economic Census[31] and U.S. Census Bureau's Manufacturing, Mining, and Construction Statistics (i.e., Construction Report, Series C30: Value of New Construction).[32] The Economic Census includes the "value of construction work" and the "value added" by industry classification (NAICS code) every five years. The "value of construction work" is the value of construction produced for sale generated by the industry, whereas "value added" is the value of construction minus the costs related to subcontracts and materials used. "Value added" more accurately describes construction output because it excludes the value added to construction by other industries. Because the Economic Census is conducted, via survey, every five years, annual construction output cannot be measured using only this census. The U.S. Census Bureau publishes monthly construction statistics as part of their Construction Reports, Series C30, that includes the "value of construction put in place." While this measure is similar to the "value of construction work" published in the Economic Census, in that, both measures provide an estimate of the value of construction work, the Economic Census measure does not include some areas of construction (e.g., nonemployer construction, architectural and engineering costs, homeowner construction).[33] While the Series C30 data provides the "value of construction work" by type of construction (e.g., commercial, industrial, etc.), it does not by industry group (i.e., NAICS code).

Economists at the National Institute of Standards and Technology (NIST) have reviewed the BLS metrics and the data types used in the manufacturing sector. Based on that review, NIST has identified a process through which industry-level metrics could, in theory, be generated for each construction industry NAICS code. This topic is covered in the Appendix, where suggested approaches for producing industry-level measures of construction productivity are discussed.

4 Factors Affecting Construction Productivity

Much has been published about the factors that affect construction productivity. Although a comprehensive treatment is beyond the scope of this white paper, several key factors are usually cited in the literature. These factors are concerned with: (1) life-cycle construction processes; (2) technology utilization; (3) skilled labor availability; and (4) offsite fabrication and modularization.

4.1 Life-Cycle Construction Processes

Management practices affect productivity over the life cycle of a construction project in a number of ways, including planning, resource supply and control, and supply of information and feedback. Management practices that are inflexible or applied inappropriately can introduce inefficiencies that reduce productivity. To address these problems, organizations such as CII have developed a suite of best practices aimed at improving the project execution process.[34] These practices are directed at all phases of the project life cycle, from design, through procurement, fabrication, construction, commissioning, and operations and maintenance.[35] In-depth analyses of the value of best practices on cost and schedule control, as well a field rework have been performed.[36] Such analyses of task and project level productivity are just getting underway, and are discussed briefly in Section 5.1.

4.2 Technology Utilization

Technology utilization impacts construction productivity in a number of ways. Historical changes in construction equipment have resulted in sustained improvements in task level productivity. Goodrum and Haas have shown that these improvements stem from better control, amplification of human energy, increased functionality, better ergonomics, and better information processing and feedback.[37] Goodrum *et al.* came to a similar conclusion regarding material characteristics that lead to reductions in unit weight and installation flexibility.[38] Preliminary analyses of CII Benchmarking data covering information integration and automation technologies revealed significant task level productivity improvements.[39] Automation technologies focus on the degree to which individual work functions (e.g., supply management and project management) are automated. Integration technologies focus on the ability to exchange information between work functions and their associated databases (e.g., exchanges of information among supply management and project management functions).

4.3 Skilled Labor Availability

One of the greatest challenges facing the construction industry is the ability to attract and retain qualified workers. This is underscored by the fact that shortages of skilled workers continue to plague the construction industry.[40] Employers have attempted to identify the root causes and to develop strategies to overcome these shortages. CII and others have funded research on the problem and generated potential solutions.[41] Despite this research and efforts to stem the problem, the construction industry's skilled worker pool continues to shrink. The decreasing number of young people entering the work force and the failure to recruit from non-traditional labor pools exacerbate this trend. Over the past 30 years, real wages of construction workers have declined relative to those of other workers. Poor industry image, tough working conditions, and the industry's perceived poor safety record also have contributed to the decline in the number of people willing to enter and remain in the industry.

4.4 Offsite Fabrication and Modularization

Prefabrication,[42] preassembly,[43] modularization,[44] and offsite fabrication[45] (PPMOF) offer potential benefits in the increasingly competitive global marketplace. Owners want better facilities faster, at the lowest possible cost, and with increased safety. Both owners and contractors view PPMOF as a means to meet challenges of demanding schedules, adverse site conditions, and limited availability of skilled labor. However, CII research shows that using these methods requires careful consideration of their implications for engineering, transportation, coordination, and project organization.[46] Recent advances in design and information technologies, combined with increasing emphasis within the industry to address cost, schedule, and labor issues, have proven the use of PPMOF to be more viable than ever. In a recent Construction Users Roundtable (CURT) publication, CII Director Wayne Crew noted that the use of PPMOF has increased in the last 10 years, especially with new technologies such as building information modeling and internet design capabilities.[47] Future workforce shortages will likely encourage the use of PPMOF. PPMOF benefits such as reduced construction time, decreased costs, and increased safety have all contributed to its popularity, and while many companies in the oil and gas industries have used it for decades, others are realizing its full set of benefits.

5 Collaborative Efforts Aimed at Improving Construction Productivity

Concerns over the perceived decline in construction productivity have stimulated interest in ways to use technology and management practices to address this challenge. Current industry efforts aimed at the seamless flow of information in an interoperable design and construction environment seek to promote labor productivity both by enabling the project team to respond quickly and effectively to new requirements, changes in scope, site conditions, and delivery delays and by promoting the use of value adding processes and technologies. The CII Strategic Plan,[48] the FIATECH Capital Projects Technology Roadmap,[49] CURT's efforts to address owner issues associated with productivity improvement and cost reduction, the American Institute of Steel Construction CIS/2 protocol, the Hydraulics Institute's initiative on electronic data exchange, and ASTM's E 57 Committee are several noteworthy examples.

5.1 Correlating Task and Project Productivity with Best Practice Use

Proponents of construction productivity metrics tend to focus on the measurement of task labor productivity. Although the value of producing task-level metrics is widely accepted, the current methodology for producing these metrics has not focused on identifying improvement opportunities. To address this issue, NIST launched a "data mining" effort in collaboration with CII's Benchmarking and Metrics Program to analyze how best practices and automation and integration technologies affect construction productivity at the task and project levels. The study will develop statistical relationships that correlate increased use of best practices and integration and automation technologies with construction productivity. Additional analyses will be conducted to correlate the combined use of best practices and integration and automation technologies on reductions in cycle time, reductions in construction cost, and reductions in field rework, which also affect construction productivity. These findings will help key industry stakeholders understand how increased use of best practices and integration and automation technologies impacts the bottom line.

5.2 Leveraging Technology to Improve Construction Productivity

CII in collaboration with FIATECH established a research team on leveraging technology to improve construction productivity.[50] Since many factors impact construction productivity, the research team adopted a three-pronged approach to better control for any external factors. First, it examined how historical changes in construction equipment, materials, and information technologies influenced improvements in construction productivity. Second, a field test of materials tracking and locating technologies was conducted to measure how using such technologies can improve productivity on prototypical CII construction projects. Previous CII research identified materials tracking and locating technologies as significant factors impacting construction productivity. Third, a predictive model that estimates the potential for a technology to have a positive impact on construction productivity was developed and tested. The predictive model addresses a technology's costs, its feasibility, its usage history, and its impact characteristics. The predictive model combines results from the historical analyses and the field test to formalize how selected technologies that have improved construction productivity can be used as a predictor of how future technologies might do the same. One of the major results of the predictive model is that as a particular technology matures, it will yield higher performance scores. Technologies with high performance scores may no longer be cutting edge, but they provide a low-risk and potentially high-reward alternative to an unproven technology. However, not all companies will limit their technology search to mature, proven technologies. The predictive model is especially valuable in identifying key characteristics of emerging technologies that provide attractive risk-reward tradeoffs. Therefore, using the predictive model to choose among alternative technology investments is the first step in leveraging technology to improve construction productivity.

5.3 Vision for the Future

A vision for the future is to develop the enabling measurement science for achieving breakthrough improvements in construction productivity that takes into account the complexity and variability of construction and leads to well-controlled, repeatable processes. This vision includes the creation of:

- Metrics and tools for measuring multifactor productivity, which explicitly model the contributions of differently-timed tasks at discrete and aggregate levels;
- Metrics for real-time control systems customized to enable the integration of emerging sensing and automation technologies for construction processes; and
- Metrics for data model alignment, protocol validation, interoperability and automated access and integration of diverse construction information systems.

A critical part of this vision is to establish an industry testbed to: (1) develop the enabling measurement science; (2) evaluate the application of the enabling measurement science to new technologies; and (3) assess the performance of new tools and processes in pilot applications under conditions similar to those found at a construction site.

Achieving the vision is more likely now because the enabling technologies are sufficiently mature to be applied to construction processes, the cost of computing is no longer a barrier, and the industry is demanding new capabilities for assessing and improving construction productivity. Leaders in the construction industry are aware of the successes and benefits[51] that have accrued from the investments in measuring and monitoring construction safety and can envision the potential for similar improvements in construction productivity. These leaders recognize that meeting the challenges of managing increasingly complex, collaborative projects with changing mixes of stakeholders and increased global competition requires the application of new measurement science to achieve breakthrough productivity improvements through integration and automation.

6 Next Steps

This white paper provides a framework for the summer 2008 National Academies Workshop for identifying and prioritizing technologies, processes, measurement science, and deployment activities which have the greatest potential to significantly advance the productivity and competitiveness of the U.S. construction industry over the next 20 years. Much is currently being done to address the underlying causes of the perceived decline in construction productivity. However, key stakeholders often have a myopic view of how to best address the underlying causes and remove barriers to change within the industry. The Workshop provides an opportunity to bring together the diverse construction industry stakeholders to identify common problems, generate consensus on ways to address some of these problems, and set priorities for attacking challenges to the industry that will require a long-term effort to address. By providing a common forum for discussion and planning, the Workshop is a first step in enabling the U.S. construction industry to achieve higher levels of efficiency and competitive advantage in the global marketplace.

Appendix Suggested Approaches for Producing Industry-Level Measures of Construction Productivity

A.1 Link Data

A potential exists for linking the detailed Economic Census with the frequent Series C30 data because both report the value of construction output by construction type. The Economic Census also reports construction output by construction type by industry classification (NAICS code). Assuming the proportions of "value of construction" for each construction type that is contributed by each industry classification remains constant in the short-term (5 years; the time between each Economic Census), then multiplying these proportions by the C30 measures of "value of construction put in place" for each industry classification provides an estimate of output by industrial classification on a monthly basis. The assumption of constant proportionality may or may not be overly restrictive in the short-term. Using previous Economic Censuses, it could be determined whether this proportionality has held in the past. An advantage of this approach is that it requires no additional data to be collected. As discussed, the disadvantage is it relies on a constant short-term division of labor between industrial classifications by construction type. Again, the accuracy of this assumption could be measured using past data. Statistics could also be updated after release of future census data.

A.2 Annual Survey

An alternative solution would be to augment the Economic Census data with a yearly sampling of construction establishments. (The construction portion of the Economic Census is based a sampling of approximately 19 % of the construction establishments that pay Federal Insurance Contributions Act (FICA) taxes.) If the Census Bureau were unable to increase their survey to an annual basis, potential exists for a smaller-scale survey to be conducted through a trade association. An advantage of partnering with a trade association would be access to construction establishments that would be willing to participate. Obviously, a disadvantage would be the potential of sample selection bias. Establishments belonging to, or active in, trade associations may not accurately represent the entire industry. A possible solution would be to calibrate the new annual statistics based on the Economic Census. This approach would be more costly than the previous (linking the Series C30 to the Economic Census); however, the added cost would likely produce more rigorous results.

A.3 Proxy Labor Wage for Output

A fundamental principle in economics states that, for profit-maximizing firms facing perfect competition, the value of the marginal productivity of an input equals its marginal cost. In a competitive labor market then, the value of marginal productivity of labor equals its wage. Labor rent seeking (the ability of labor to charge a higher wage than the value of its marginal productivity) is eliminated due to competitive market forces. Simply put: for the same level of productivity, lower-priced labor will out compete higher-priced labor. Data exists to track labor wage over time. The BLS CES survey provides annual statistics on the "average hourly earnings of production workers" by industry classification. R.S. Means reports national labor wages by specialty, and the bare material and equipment costs. For example, Allmon *et al*.[52] and Johannes *et al*.[53] use R.S. Means data to explore productivity. This principle holds for other factors of production (e.g., capital and equipment) and could be a big advantage in calculating multifactor productivity.

An advantage using this proxy is that the productivity measure is based on value added and not value of construction put in place. The former value is an accurate value of production, whereas the latter includes value added from other stages of production. Multifactor productivity can be measured as the sum of each input's unit costs used in production.

A possible shortcoming of measuring productivity using wage and input prices is the required assumption of perfect competition. The fact that the construction industry is populated by many small construction firms operating on small profit margins, suggests that the industry may be fairly competitive. But the presence of labor unions indicates that the industry is not perfectly competitive. Estimating econometric models of labor demand could be used to investigate the determinants of labor wages, and evaluate how factors such as unionism, regional differences, and market size affect competitive wages.

---

[1] Bureau of Economic Analysis. "Gross-Domestic-Product-(GDP)-by-Industry Data." *Industry Economic Accounts* (Washington, DC: Bureau of Economic Analysis), http://www.bea.gov/bea/dn2/gdpbyind_data.htm (accessed March 2008).

[2] United States Census Bureau: Manufacturing and Construction Division. "Annual Value of Construction Put in Place." *Current Construction Report (CCR) C30 (*Washington, DC: United States Census Bureau, July 3, 2007), http://www.census.gov/const/C30/total.pdf (accessed March 2008).

[3] The value for maintenance and repair is calculated by using the ratio of maintenance and repair to new construction put in place from the 1997 census and multiplying it by the current value for new construction put in place.

[4] The value of manufactured products, materials, components, and systems is calculated using ratios from the 2002 census. United States Census Bureau. "2002 Economic Census: Construction Subject Series." *Industry General Summary: 2002*. EC02-23SG-1 (Washington, DC: U.S. Census Bureau, October 2005).

[5] Contents and furnishings is the sum of values for 2004 furniture and related product manufacturing (NAICS 337), carpets and rug mills (NAICS 314110), curtains and linen mills (NAICS 31412), audio and video equipment manufacturing (NAICS 334310), lighting fixture manufacturing (NAICS 33512), small electric appliance manufacturing (NAICS 335211), household cooking appliance manufacturing (NAICS 335221), household refrigerator and freezer manufacturing (NAICS 335222), and household laundry equipment (NAICS 335224) adjusted to 2006 using the consumer price index for all consumers. United

States Census Bureau. *Statistics for Industry Groups and Industries: Annual Survey of Manufactures* (Washington, DC: U.S. Census Bureau, December 2006) 6, 25, 27, 31.

[6] The total of energy, water, and services is the total of commercial sector energy (from the Energy Information Administration), residential energy (from the Energy Information Administration), commercial water use (from the USGS), and residential water use (from the USGS) adjusted to 2006 dollars.

[7] United States Bureau of Labor Statistics. "Household Data: Employed Persons in Nonagricultural Industries by Sex and Class of Worker." *Current Population Survey* (Washington, DC: Bureau of Labor Statistics), http://www.bls.gov/cps/cpsaat16.pdf (accessed March 2008).

[8] *Ibid*.

[9] Civil Engineering Research Foundation. *A Nationwide Survey of Civil Engineering-Related R&D.* CERF Report #93-5006 (Reston, VA: American Society of Civil Engineers, 1994).

[10] http://www.nsf.gov/statistics/infbrief/nsf07335/ (accessed March 2008).

[11] Teicholz, Paul. "Labor Productivity Declines in the Construction Industry: Causes and Remedies." *AECbytes Viewpoint*. Issue 4. April 14, 2004.

[12] Young, Norbert W. Jr. and Harvey M. Bernstein. "Key Trends in the Construction Industry – 2006." *SmartMarket Report* (New York, NY: McGraw Hill Construction, July 2006) 8.

[13] Construction Users Roundtable. "Pre-Assembly Perks: Discover Why Modularization Works." *The Voice*. (Fall 2007), pp 28-31.

[14] Allen, Steven G. "Why Construction Industry Productivity Is Declining." *The Review of Economics and Statistics*. Vol. 67 (1985), pp. 661-669.

[15] Stokes, H. Kemble, Jr. "An Examination of the Productivity Decline in the Construction Industry." *The Review of Economics and Statistics*. Vol. 63 (Nov. 1981), pp. 495-502.

[16] Goodrum, Paul M. and Carl T. Haas. "Partial Factor Productivity and Equipment Technology Change at Activity Level in U.S. Construction Industry." *Journal of Construction Engineering and Management*. Vol. 128 (Nov./Dec. 2002), pp. 463-472.

[17] Faruqui, Umar, Wulong Gu, Mustapha Kaci, Mirielle Laroche, and Jean-Pierre Maynard. "Differences in Productivity Growth: Canadian-U.S. Business Sectors, 1987-2000." *Monthly Labor Review*. Vol. 126 (April 2003), pp. 16-29.

[18] Tulacz, G. and T. Armistead. "Top Owner – Large Corporations Are Attempting to Meet the Industry Halfway on Issues of Staff Shortages and Risk." *Engineering News Record* (November 26, 2007).

[19] Construction Industry Institute. *Benchmarking and Metrics Value of Best Practices Report*. BMM2003-4 (Austin, TX: Construction Industry Institute, 2003).

[20] Construction Industry Institute. *Strategic Plan* (Austin, TX: Construction Industry Institute, 2005).

[21] FIATECH. *Capital Projects Technology Roadmapping Initiative* (Austin, TX: FIATECH, October 2004).

[22] The term ***measurement science*** includes: (1) the development of performance metrics, measurement methods, predictive tools, and protocols as well as reference materials, data, and artifacts; (2) the conduct of inter-comparison studies and calibrations; (3) the evaluation and/or assessment of technologies, systems, and practices; and (4) the development and/or dissemination of technical guidelines and basis for standards, codes, and practices -- in many instances via testbeds, consortia, and/or other partnerships with the private sector.

[23] Weber, Stephen F. and Barbara C. Lippiatt. *Productivity Measurement for the Construction Industry*. NBS Technical Note 1172 (Gaithersburg, MD: National Bureau of Standards, February 1983).

[24] R.S. Means. *Building Construction Cost Data: 2006*. 64th Edition. (Kingston, MA: R.S. Means, 2005).

[25] Stephen P. Mulva, Associate Director for Benchmarking and Metrics, Construction Industry Institute, personal communication.

[26] Bureau of Labor Statistics. "Chapter 11. Industry Productivity Measure." *BLS Handbook of Methods* (Washington, DC: Bureau of Labor Statistics, 1997), pp. 103-109.

[27] *Ibid*.

[28] *Ibid*.

[29] Allmon, Eric, Carl T. Haas, John D. Borcherding, and Paul M. Goodrum. "U.S. Construction Labor Productivity Trends, 1970-1998." *Journal of Construction Engineering and Management*. Vol. 126 (Mar./Apr. 2000), pp. 97-104.

[30] Bernstein, Harvey M. "Measuring Productivity: An Industry Challenge." *Civil Engineering* (Dec. 2003), pp. 46-53.

[31] United States Census Bureau. "2002 Economic Census: Construction Subject Series." *Industry General Summary: 2002*. EC02-23SG-1 (Washington, DC: U.S. Census Bureau, October 2005).
[32] United States Census Bureau: Manufacturing and Construction Division. "Annual Value of Construction Put in Place." *Current Construction Report (CCR) C30 (*Washington, DC: United States Census Bureau, July 3, 2007).
[33] Cole, Tamara. "Reconciling Construction Data, A Comparison of the Value of Construction Put in Place Series, the 1997 Economic Census and the 1998 Annual Capital Expenditure Survey." (Washington, DC: U.S. Census Bureau, May 2002).
[34] For a list of CII knowledge areas, practices, and information resources, see: http://www.construction-institute.org/source/Orders/CII_Matrix.cfm?section=orders&OrdersSection=Matrix
[35] Construction Industry Institute. *Design for Maintainability: Improving Project Return on Investment*. RS142-1 (Austin, TX: Construction Industry Institute, 1999).
[36] Construction Industry Institute. *Benchmarking and Metrics Value of Best Practices Report. Op cit*.
[37] Goodrum, Paul M. and Carl T. Haas. *Op cit*.
[38] Goodrum, Paul M., M. Yasin, and Z. Dong. "The Relationship Between Changes in Material Technology and Construction Productivity." Mimeo. (Lexington, KY: University of Kentucky).
[39] Construction Industry Institute. *Leveraging Technology to Improve Construction Productivity*. RS 240-1 (Austin, TX: Construction Industry Institute, forthcoming).
[40] Construction Industry Institute. *The Shortage of Skilled Craft Workers in the U.S*. RS 182-1 (Austin, TX: Construction Industry Institute, 2003).
[41] *Ibid.*
[42] Prefabrication: a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation.
[43] Preassembly: a process by which various materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation as a sub-unit; generally focused on a system.
[44] Module: a major section of a plant/building resulting from a series of remote assembly operations and may include portions of many systems; usually the largest transportable unit or component of a facility.
[45] Offsite fabrication: the practice of preassembly or fabrication of components both off the site and onsite at a location other than at the final installation location.
[46] Construction Industry Institute. *Prefabrication, Preassembly, Modularization, and Offsite Fabrication in Industrial Construction: A Framework for Decision-Making*. RS 171-1 (Austin, TX: Construction Industry Institute, 2002).
[47] Construction Users Roundtable. "Pre-Assembly Perks: Discover Why Modularization Works." *Op cit*.
[48] Construction Industry Institute. *Strategic Plan. Op cit.*
[49] FIATECH. *Capital Projects Technology Roadmapping Initiative. Op cit.*
[50] Construction Industry Institute. *Leveraging Technology to Improve Construction Productivity*. *Op cit*.
[51] Construction Industry Institute, *2007 Safety Report.* BMM2007-2 (Austin, TX: Construction Industry Institute, 2007).
[52] Allmon, Eric, Carl T. Haas, John D. Borcherding, and Paul M. Goodrum. *Op Cit*.
[53] Johannes, James M., Paul D. Koch, and Robert H. Rasche. *An Investigation of Factors Affecting Geographical Cost Differentials on Military Construction Projects*. NBS GCR 80-197 (Gaithersburg, MD: National Bureau of Standards, 1980).