Research Opportunities for Construction Industry Project Level Productivity Management Tools

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Using meta-analysis technique, this paper explores the present status of commonly used practitioner-based construction productivity tools and proposes future opportunities for meaningful academic research within the same domain. The paper outlines primary characteristics of commonly used productivity management tools; classifies productivity management tools by functionalities, maps applicable strengths and weaknesses, describes usage constraints and opportunities, elaborates upon potentials to expand industry usage, identifies subsequent areas of academic research, and offers a direction for future research.

Key Words: Productivity, Performance, Measurement, Management, Tools

Introduction

The construction industry in the US accounts for more than five percent (5%) of the country's gross domestic product (Bureau of Economic Analysis, 2012) and employs approximately seven percent (7%) of its workforce (as of 2013). Productivity of a major sector like construction, thus, has a significant impact on the national economy and generates inquiries from industry and academia alike. The nature of the construction projects makes it difficult to measure productivity in construction (Sweis, 2000). Part of the problem is due to lack of comparable input and output data among varying construction projects (Finkel, 1997); it is difficult to compare single-family houses to roads, schools to bridges, or office buildings to shopping centers.

There is a dearth of reliable and meaningful information on construction industry productivity owing to lack of suitable productivity measures of construction activities, which can be inferred from the US Bureau of Labor Statistics not maintaining any productivity index for the construction industry, (Nasir et al., 2014). Thus, industry analysts remain divided on improvement or decline in construction industry productivity. Some industry analyses indicate that productivity has been declining for over 30 years while other studies document improved construction productivity (National Research Council, 2009). *Rethinking Construction*, a (DETR, 1998) report published by the Construction Task Force in UK, echoed that reliable data on performance in terms of productivity is hard to come by and suggested that the construction industry must put in place a means of measuring progress towards its objectives and targets.

This conference paper intends primarily to open dialogue on potential research opportunities in productivity measurement/management. It is not a definitive study nor is it all-inclusive analysis of the topic. Regardless of the disparities and dearth of reliable data on construction productivity, the construction companies need performance management tools that are relevant in order to improve their performances. In this paper, the authors have attempted to study productivity management tools applicable at the project level specific to construction. First, the paper provides a brief discussion about the current state of productivity management research in the construction industry; followed by a review of leading industry project level measurement tools. Leading industry tools refer to tools validated by their acceptance in the industry through the literature or practice. The paper continues by comparing the different tools in regards to the levels, limitations, and research opportunities these productivity measurement/management tools provide.

Recent Research in Productivity Management Tools

In the late 1980s, no standard definition of construction industry productivity existed (Thomas and Mathews, 1986). The lack of standard definition and guidelines forced the companies to use their internal metrics that are not standardized. In generic terms, an association between input and output can illustrate productivity. While productivity information can be successfully computed at the project level. Aggregating data to an industry level causes the loss of valuable information regarding the heterogeneous nature of construction outputs (Abdel-Wahab and Vogl, 2011). In construction, productivity is operations based with inputs and outputs recorded as operations progress.

After a period of solely relying on financial measures to appraise project performance, industry and academia realized the need for non-financial measures in conjunction with financial measures to present holistic appraisal of projects. As a result, several researchers proposed performance management metrics that took into consideration both financial and non-financial measures (Keegan et al., 1989, Cross and Lynch 1988/89). Cross and Lynch (1988) in particular prescribed underlying relationships among the basic performance criteria (performance dimensions) in the performance pyramid shown in Fig. 1.

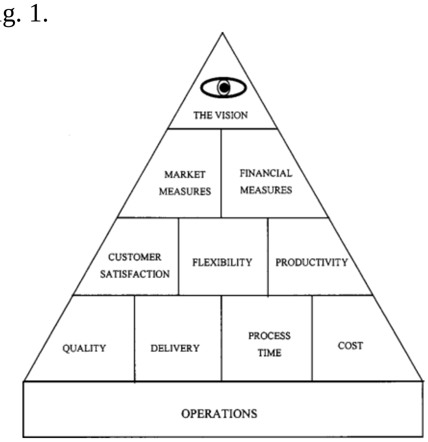

Figure 1: The Performance Pyramid – Cross and Lynch (1988)

An initial review of the available literature on construction productivity revealed several studies that identify critical factors affecting construction productivity. In 1988, Chau and Walker suggested a list of variables they termed "construction productivity influence factors" which construction firms must manage. In a study conducted by Herbsman and Ellis (1990), they categorized critical factors affecting construction productivity as technological and organizational influence factors. Technological influence factors include specifications, design, location and materials. While organizational factors comprised of production, labor, and social factors.

With considerable number of studies focused on identifying factors affecting construction productivity, there is a lack of literature that attempt to synthesize the existing body of knowledge in productivity research. An example of such attempt is the recent work of Yi and Chan (2014), which identified the common themes in construction labor productivity (CLP) research, such as modeling and evaluation of labor productivity and trends and comparisons of labor productivity. Similarly, Dolage and Chan (2014) did an extensive study finding that although construction productivity research focused on the measurement of productivity" it lacked scholarly attention toward blue-collar worker perspective and employee involvement. The authors' also support this conclusion. Therefore, the authors' hope that by reviewing commonly used productivity measurement/management tools, their challenges in use and the associated opportunities for research into simple 'blue-collar' management tools, academics can begin to bridge a recent research gap identified by Bigelow, et.al. (2016) that academics and industry is disconnected.

Methodology

The authors' conducted a meta-analysis review to identify and investigate the current state of productivity research within the domain of productivity management tools. The five steps in the study are as follows.

1. Identify common construction industry operational level productivity measurement/management tools
2. Validate the selected tool sample through a longitudinal survey of the literature
3. Categorize these tools into broader research areas
4. Conduct a strength/weakness assessment of each tool
5. Identify, quantify, and assess the scope of recent research on productivity measurement/management tools

Common Productivity Measurement Management Tools

As identified by Illingsworth (2000) construction is composed of only two fundamental production activities. These two activities are 1) handling of material & equipment, and 2) the positioning of materials and equipment to produce the whole. The appropriate operational detailed planning of these activities are key determinants for efficient production. As such, the industry has created multiple tools to assist in measuring, monitoring, and predicting the operational performance of construction operations. Recent research findings indicate that general contractors perceive that research into construction productivity is of the highest value (Bigelow, et. al., 2016).
One of the enduring constants in measuring productivity in construction operations is the recognition of hourly outputs. Therefore, labor hour inputs are a reliable and commonly used metric for measuring labor productivity. Thus the common equation measuring labor productivity (LR) is LR = Output (Units) ÷ Labor Hours (LH) = Units/LH. Measuring and managing productivity at the project level can present a challenge as construction's output measurement are typically a function of the units measured to a specific construction activity, e.g., excavations are commonly measured in cubic yards (CY) whereas masonry walls are measured in square feet (SF). To simplify and compensate for this difficulty in transformation, construction professionals can define labor productivity as a ratio of actual over expected productivity, expressed mathematically as Performance Ratio (PR) = Actual Productivity (LH) ÷ Expected Productivity (LH) with a PR>1meaning lower productivity, more work hours required than expected.
To assist and support construction managers and supervisors, the industry has developed a variety of productivity measuring and monitoring techniques and tools. Based on industry familiarity and observational use of industry based field productivity measurement tools the authors selected the following tools that if researched and further refined, could lead to opportunities to optimizing productivity and greater industry use.

Table 1

Identifiable Productivity Measurement Management Tools

Critical Path Method (CPM)	Last Planner/Percent Plan Complete	Process Maps
Cycle Time Analysis	Weighted Production Valuations	Commodity/Trend Charting
Earned Value Analysis (EVA)	Productivity Achievement Ratio (PAR)	Short Interval Planning Schedules (SIPS)
Work Sampling	Time Studies	Visual Modeling/Simulation
Budget Reports	Variance Reports	

Validation of Selected Tools

To validate the authors' initial selection of common productivity measuring/monitoring/management tools, a 5-year longitudinal review of the literature across four peer reviewed construction management journals was done. The four peer reviewed construction management journals were, *International Journal of Construction Education and Research (IJCER), Journal of Construction Engineering and Management (JCEM), Journal of Construction Management and Economics (JCME), and Automation in Construction (AC),* within years, 2012 – 2016. The 5-year search window is to maintain immediacy and relevance in the research. Journal selection was based on the authors' self-assessment of journal penetration and reputation in academia and to cover construction related fields of education, engineering, management, economics, automation, and contemporary information communications technology. This article searches were done through online searches within each journals online website using the text in Table 1 as keyword and title search phrases in addition to using the text 'productivity', 'productivity improvement,' 'production,' 'labor productivity,' and 'field measurement.' Due to early validation efforts, the search term 'simulation' was added and the results codified based on pertinence to construction productivity. Simultaneous with the validation of the identified tools individual research articles were categorized based on tool relevance. Manual culling of any non-tool related article was done followed by quantification and categorization.

Categorization of Selected Tools

The productivity side of the Performance Pyramid (Cross and Lynch 1988) allows a structural approach to categorizing operation based productivity tools within more expansive and conceptual research type domains - process time, cost, productivity, and financial measures. These specific domains were selected on their specificity to productivity improvement. Using insights from Cross and Lynch (1988), each domain is briefly defined in their applicability to productive construction operations. The specific type domains used to link construction processes to the research are:

- **Process Time:** The time the process or operation takes to deliver added value to the product. Examples tools are CPM, Last Planner/PPC, Process Maps, and Cycle Time Analysis.
- **Cost:** The money (or effort) spent to achieve added value. Examples tools are weighted production valuations, commodity/trend charting, budget reports.
- **Productivity:** The most cost-effective and timely means of achieving value-added end goals. Examples tools are PAR's, SIPS, work sampling, time studies, visual modeling/simulation.
- **Financial Measure:** Positive cash flow and profitability of the process or operation. Examples tools are variance reports and EVA.

Strength and Weakness Assessment

Using the authors' professional experiences and insights from the meta-analysis of the literature, Appendix A was prepared to outline the fundamental strengths/weaknesses for each tool. A proactive or reactive designation was assigned to each tool depending on the timing of its initial opportunity to influence productivity improvement. This designation, perceived from the authors' experience, is indicative of the tools' operational value.

Findings

Appendix B quantifies the number of articles by type and tool while identifying proposed research opportunities. Eighty-five (85) articles on productivity management/measurement tools were published within the four selected journals over the last five years. Published research into Process Time accounts for 45% of the published research (38 articles), Productivity is 40% (34 articles), Financial Measures is 13% (11 articles), and published research on Cost Management/Measurement tools represents 2% (2 articles) of the published articles. Additional conclusions drawn from the investigation is that the published research is strongly focused on two main thrusts, Lean Practices, via Last Planner/Planned Percent Complete (PPC) and Short Interval Planning Schedules (SIPS) (29% of published articles), and Visual Modeling/Simulation (33%). There is concern that the Visual/Modeling/Simulation results are skewed based on the inclusion of the journal Automation in Construction, which focuses on computer related research highly applicable to building information modeling (BIM) and computer simulation. Two tools (Commodity/Trend Charting and Variance Reports) show no published research.

Research Opportunities

Bigelow et. al. (2016) has identified disconnects between industry needs and academia research particularly on productivity. Appendix B identifies some proposed directions for research in enhancing productivity measurement/management. In summary, the authors believe that more practical 'blue-collar' based productivity research can focus on the use of universally collected cost and financial data particularly in research aimed at integrating cost, finance, and productivity. These domains are functional components of all field-managed controls. Specific research into the integration of weighted production valuation, budget/variance reports, and PAR's (currently at 4%) with *simplified* earned value analysis (EVA) tools (at 13%) offers practical 'boots on the ground' blue collar research easily adopted and used by industry. Further research efforts can focus on visualization techniques to increase productivity in presenting the results from these integrated tools. In conclusion, the authors believe there exist ample tools in productivity management/measurement domains to provide future research opportunities for linked connectivity of commonly used but fragmented tools, i.e., management tools that capture and record performance data tied to productivity but lack good linkages back to supporting field productivity. As such, it is up to construction academicians to recognize the practicality of commonly used industry tools and integrate them into their research.

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Appendix A - Common Productivity Management Measurement Tools

Type	Tool	Description	Strength	Weakness
Process Time: Time the process takes to deliver a value-added product.	CPM	Logical sequencing of time related milestone tasks.	Allows a milestone focus on the 'when" in identifying the start and finish of larger scope packages.	**Reactive**: End date driven and does not identify resources constraints or causes of poor performance.
	Last Planner/% Plan Complete (PPC)	Effort driven detailed work commitments that are measured for accountability	**Proactive:** Allows planning at the detailed workface level by workers	Requires collaborative buy-ins and accountability of commitment
	SIPS	Highly detailed short-term linear daily work schedule prepared in bar chart format and agreed to by the trades that identifies work location, crews, and actual work to complete.	**Proactive:** Easy to comprehend and visualize the time interface among multiple trades and their workflow across multiple work locations.	Not all project types lend themselves to high volume production applicable to SIPS.
	Process Maps	Graphical mapping or work processes used to identify repetitive cycles, redundancy, and bottlenecks	**Proactive:** Graphical tool allowing easy visualization of input/output processes, and resource needs.	Requires comparative trail runs of alternative processes.
	Cycle Time Analysis	Methodical approach to time data collection and analyzes time data for predicting cyclic process performance.	**Proactive:** Predictive nature and easy to use. Easily adjustable variable outputs able to create multiple performance scenarios.	Limited utilization, primarily for operations that have distinct and observable cycles.

Type	Tool	Description	Strength	Weakness
Cost: Money (or time) spent to achieve added value.	Weighted Production Valuations	A cost reporting methodology that weights different tasks within an operation to allow insight into how an operation containing mixed units is performing.	Simultaneously incorporation of costs and labor hours into a single variance style report to identify internal operational tasks that are degrading performance.	**Reactive:** For maximum value requires accurate daily reporting and analysis.
	Commodity / Trend Charting	Graphical representations of the trends of daily work outputs.	**Proactive:** Visually easy to read and simple to determine status of production, productivity, and comparison of current to expected performance.	Requires frequent and continuous updating from accurate inputs.
	Budget Reports	Comprehensive status reports that identify daily, weekly, and monthly cost and/or labor hours.	Commonly produced at varying frequency with high familiarity.	**Reactive:** Primary focus is on status and they are delay dependent and lack adequate granularity to enhance labor productivity.

Type	Tool	Description	Strength	Weakness
Productivity: Most cost-effective and timely means of achieving end goals.	PAR	Comparative ratios that measure management effectiveness through actual productivity against a measured exemplary or a theoretical optimal.	Allows comparisons to prioritize crew performances and their management needs on single or multiple projects in addition to crew productivity trends.	**Reactive:** Not widely utilized with a high learning curve in analysis hindering effective management response.
	Work Sampling	Statistical technique to determine the proportion of time workers spend doing various defined categories of work	**Proactive:** Quick effective technique to recognize, analyze, and enhance workers contribution and responsibility toward task completion.	Time to collect, frequency of data collection, and collector decisions could lead to a deficiency in data collection and thus analysis.
	Time Studies	Continuously timed and recorded task observation.	**Proactive:** Similar to work sampling but with more frequent data points and a higher level of data reliability.	Behavior changes as a result of continuous observations
	Visual Modeling/Simulation	Visually realistic, symbolic, or simulated modeling of a construction product (building systems) or process.	**Proactive:** Easy to comprehend and visualize the interface among multiple systems.	Requires specialize software and compatible applications

Type	Tool	Description	Strength	Weakness
Financial Measure: Positive cash flow and profitability	Variance Reports	Identify the differences between planned and actual outcomes.	Commonly used construction management tools that works well as a part of most organization's existing financial measures	**Reactive:** Looking backward at the status of previous performance.
	EVA	Method of contemporaneously measuring a project's cost and schedule performance and forecasting final completion dates and costs.	A broad real-time insight into both costs and labor performance with an ability to forecast final project costs and time to complete. Used by sophisticated organizations that employ cost engineers.	**Reactive:** Relies on the accuracy of previously capture data and is weak on productivity measures.

Appendix B - Research on Productivity Measurement Management Tools

Type	Tool	2012 - 2016 Articles JCEM	IJCER	JCME	AC	Research Opportunity
Process Time: Time the process takes to deliver a value-added product.	CPM	4	1	0	1	More real world applications of alternative methods such as Location Based Scheduling to identify hidden buffers. Greater incorporation of resource loading at the crew level.
	Last Planner/PPC	6	3	4	1	Better analytical feedback in work batching to allow a balanced flow of ready work, research into PPC acceptance and value.
	SIPS	0	2	1	8	Case studies applied to repeating workflow, like hotel rooms, dormitories, schools classrooms, and hospitals.
	Process Maps	1	0	0	2	Integration of time data inputs to allow alternative graphical perspectives.
	Cycle Time Analysis	2	0	1	1	Use production cycles to identify and separate value-added from non-value added work, for process improvements and cycle inefficiencies. Advanced programmable simulation tools to predict systems productivity.
Cost: Money (or time) spent to achieve added value.	Weighted Production Valuation	1	0	0	0	Incorporating EVA into operations to determine cost and schedule performance, and then predict outcomes.
	Commodity / Trend Charting	0	0	0	0	Case study in field application to distinctively linear or repetitive operations.
	Budget Reports	0	0	1	0	Extending data capture into status report for proactive insights into project performance.

**Productivity: ** Most cost-effective and timely means of achieving end goals.	PAR	0	0	1	1	Opportunity for quick prioritization of field management performance linked to budget, variance reports, and weighted production valuation.
	Work Sampling	0	0	0	1	Using manual or automated video data capture for case examples involving crew intensive operations. Field studies of factors that affect craft time utilization and development of algorithms that can accurately predict from limited data sets.
	Time Studies	2	0	1	0	Using video data capture for case examples involving crew intensive operations.
	Visual Modeling/Simulation	8	3	2	13	Utilize low cost software applications in the field to produce 3-D relational visualization
Financial Measure: Positive cash flow & profitability	Variance Reports	0	0	0	0	Increase breadth of variance reports for *simplified* EVA approaches.
	EVA	9	0	0	2	Find simple tools that link EVA into budget reporting, variance, weighted production, and BIM.