Benchmarking of Construction Productivity

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Abstract: Construction productivity has been a cause of great concern in both the construction industry and academia. Even though many companies have developed their own productivity tracking systems based on their experiences and accounting systems, none have been successful in establishing common definitions and developing a survey tool that collects standard productivity data at the appropriate levels. This research was initiated to establish a common set of construction productivity metrics and their corresponding definitions. As a result of this research effort, the Construction Productivity Metrics System (CPMS), which contain a list of direct and indirect accounts and 56 data elements grouped into seven major categories, was developed. The Construction Productivity Metrics System is a standard construction productivity data collection tool and provides a framework to report industry norms to benchmark construction productivity. Input from 73 industry experts was used in determining the 56 measuring elements and their corresponding definitions. Preliminary findings from initial sample of 16 industrial projects indicate that the productivity metrics can be produced and should be meaningful for construction productivity benchmarking. Because of the small sample size, more than general preliminary conclusion would be inappropriate. Based on the analyses, the developed CPMS is believed to be a reasonable productivity data collection tool and when sufficient data are available should be capable of producing reasonable industry benchmarks.

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Introduction

Because the business environment in construction is highly competitive, the participants in the industry must improve construction productivity performance to survive. Hence, productivity has been generating significant interest in both the construction industry and academia. As The Business Roundtable Construction Industry Cost Effectiveness (CICE) Project report documented the requirement for a means of measurement and comparison with others to improve construction productivity (BRT 1982). However, most previous studies focused on defining factors that influence productivity and on measuring limited parts of activities at a microlevel to investigate the relationship between factors and productivity. Those studies also lacked standard definitions of categories and activities.

A reliable standard construction productivity metrics system is a critical element in construction productivity performance evaluation and the improvement process. Owners need a means to evaluate the performance of contractors on their capital facility projects. Contractors need a tool to drive performance improvement through internal or external benchmarking. Measurement may not directly lead to performance improvement, however, performance improvement over time can be achieved through recognizing the need for improvement.

Demand from the construction industry to develop acceptable construction productivity metrics has driven this research. Researchers have stressed the importance of standardized productivity data (Thomas and Yiakoumis 1987) and Construction Industry Institute (CII) member organizations have long proposed the need for such metrics. This research describes efforts directed toward developing a common tool that collects standardized construction productivity data for benchmarking and eventually productivity improvement.

This research mainly focuses on the development of a standard construction productivity metrics system. More specifically, the research objectives are: (1) to establish a common set of construction productivity metrics and their corresponding definitions and (2) to establish a format for reporting norms for construction productivity performance metrics.

The development of this metrics system was based primarily on large process projects. Therefore, the outputs from this research are most applicable to heavy industrial projects. The framework of this metrics system and development methodology, however, may be applied to other sectors such as light industrial, building, and infrastructure. Also, several metric categories such as concrete and structural steel are applicable to all industry sectors.

Background of Construction Productivity Metrics System

The literature review of previous research is provided into two sections. The first section begins with brief definitions of produc-

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tivity. The second section is devoted to addressing the productivity measurement systems.

Definition of Productivity

Back in 1986, Thomas and Mathews (1986) stated that no standardized productivity definition had been established in the construction industry. It is difficult to define a standard productivity measure because companies use their internal systems which are not standardized.

Productivity can be simply illustrated by an association between an output and an input. Two forms of productivity were used in previous industry studies: (1) productivity=output/input and (2) productivity=input/output. The second form has been widely used and existing in literature over the years in the construction industry. Therefore, this research adopted the second form to maintain consistency with other productivity research in construction and CII benchmarking and metrics (BM&M) performance indices like cost growth and schedule growth in which a lower value represents better performance

$$\text{labor productivity} = \frac{\text{input}}{\text{output}} = \frac{\text{actual work hours}}{\text{installed quantity}} \qquad (1)$$

As shown in the above equation, labor productivity is measured in actual work hours per installed quantity; that is, the number of actual work hours required to perform the appropriate units of work and as noted, when defined in this manner, lower productivity values indicate better productivity performance.

Productivity Measurement in Construction

Although numbers of publications exist on construction productivity, there is no agreed upon definition of work activities nor a standard productivity measurement system. Researchers have concluded that it is difficult to obtain a standard method to measure construction labor productivity because of project complexity and the unique characteristics of construction projects (Oglesby et al. 1989). The uniqueness and nonrepetitive operations of construction projects make it difficult to develop a standard productivity definition and measure (Sweis 2000). A few researchers have attempted to develop common definitions and a standard productivity system; however, those were not based on the consensus of academia and industry.

The CICE Project report reviewed construction productivity measurement procedures and then recommended that productivity measurement programs should be established (BRT 1982). In 1990, CII developed a productivity measurement system that includes a reporting system, an output and input measuring system, and a performance evaluation system to measure site-level productivity (CII 1990). Adrian and Boyer (1976) established the method productivity delay model to measure, predict, and improve the productivity of a given construction method. Weber and Lippiatt (1983) reviewed the methods for measuring single factor productivity and total factor productivity in construction. Thomas and Yiakoumis (1987) described the factor model that contains environmental, site, management, and design factors for structural steel and masonry formwork activities. Sanders and Thomas (1993) further identified factors such as construction methods, design requirements, and weather that affect masonry productivity and investigated the effect of factors using the factor model with data obtained from standardized collection procedures. Another model, the action–response model, also provides a framework for evaluating the causes of productivity loss on projects to mitigate or eliminate the loss of productivity (Halligan et al. 1994). The CII research report also documented the factors that could affect craft worker productivity such as engineering/design, site conditions, materials, construction management, and labor problems (CII 2001).

As Liou and Borcherding (1986) determined, productivity measurement is not a one-time task. Continuous measurement and comparison with other projects or companies are the keys to productivity improvement. Thomas and Yiakoumis (1987) stressed the importance of a standardized productivity data collection system to provide reliable analyses.

The productivity measurement research studies mentioned above have focused on how to report, measure, control, evaluate, and improve construction productivity. Yet, those studies lack a common set of definitions of activities and a standard data collection method. Furthermore, the existing productivity measurement systems have focused on microlevel activities to manage daily or monthly productivity during construction and that are tied to a sophisticated cost control system that is too complex to track and evaluate construction productivity. The construction productivity metrics system (CPMS) in this paper uses common definitions to establish industry productivity norms that can be utilized as a benchmarking tool over years.

Development of Metrics

The CII BM&M committee has established the basic framework for data collection and analysis over the course of its lifetime of CII. Performance metrics include cost, schedule, safety, changes, and rework. The CII benchmarking research has revealed that construction performance has been impacted by best practice use (CII 2002, 2003). Accordingly, this research follows the basic guidelines and incorporates with the current CII benchmarking system.

Historically, there has been an acknowledged need for a standard CPMS that includes the overall construction work activities of a project. Various researchers have addressed this need, but efforts at developing such a system have been inconsistent.

The productivity metrics group was established in 2000 to produce standard construction productivity metrics so that owner and contractor organizations can better perform internal and external benchmarking on productivity (Park 2002). This main research objective has been achieved by establishing construction productivity metrics that consist of direct and indirect accounts, seven metric categories and 56 measuring elements, and their related definitions.

The direct and indirect account list and 56 measuring elements under the seven broad categories and definitions were identified through the use of literature reviews, documentation from owner and contractor organizations, the experience of productivity metrics group members, and a series of workshops with industry experts. A consensus was reached on the reasonable and appropriate level of measurement and related definitions among the workshop participants. The definitions and categories were developed into the construction productivity questionnaire. The construction productivity questionnaire was reviewed during productivity workshops, questionnaire streamlining meetings, BM&M committee meetings, and BM&M associate training sessions. After minor modifications, the construction productivity questionnaire was recently formally included into the CII BM&M questionnaire.

From June 2000 to March 2002, eight workshops were hosted.

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Table 1. Research Milestones

Date	Outputs
June 2000	• Establish path forward
July 2000	• Identify and discuss issues
	• Develop work plan and resource team
September 2000	• Establish seven construction metric categories and preliminary construction metric definitions
	• Develop direct and indirect accounts
November 2000	• Review construction metric categories and definitions
February 2001	• Finalize construction metric categories and definitions
June 2001	• Finalize first draft of construction metric questionnaire
	• Initiate pilot data collection
October 2001	• Validate construction metric questionnaire
January 2002	• Finalize construction metric questionnaire
	• Discuss data collection
March 2002	• Open previously submitted projects for data collection

A total of 73 experienced industry professionals were involved to identify the metric categories, the definition of elements within, and to determine the appropriate level of detail for the questionnaire developed. Table 1 summarizes milestones of construction productivity metrics development. The table describes the process used for development of the construction productivity metrics questionnaire. These workshops were not only beneficial in terms of establishing a set of common metric definitions, but also provided an opportunity to discuss the need for a CPMS. The CPMS mainly focused on heavy industrial projects because most workshop participants were from the heavy industrial sector. Therefore, seven categories: concrete, structural steel, electrical, piping, instrumentation, equipment, and insulation, were decided based on heavy industrial construction project.

This paper describes the list of direct and indirect accounts, the construction productivity metrics for seven categories, and their corresponding definitions.

Direct and Indirect Accounts

A common set of definitions of direct and indirect accounts is necessary to collect standardized construction productivity data. Because each organization has a different cost control system, a consensus on direct and indirect account is important to induce the participation and to provide reliable analyses. This list of direct and indirect accounts was developed based on the knowledge of industry experts and documentation of the participating organizations. To achieve a consensus on the list of direct and indirect account, several workshops were held. The participants compared several account systems provided by CII member companies and reached the list of direct and indirect accounts shown in Table 2. Because each company uses its own accounting system, it was a long and difficult process to achieve consensus on the list of direct and indirect accounts. Among the various accounts, nine accounts were assigned as direct accounts. All the other accounts are decided as indirect accounts and excluded from computing work hours. Existing productivity measurement systems have used work hours from payroll reporting systems. However, criteria to calculate work hours in payroll reporting systems differ. Therefore, comparison of productivity with other companies is meaningless without a standard list of direct and indirect accounts. This account list was developed to overcome this obstacle to benchmark productivity.

Actual work hours are computed by the summation of all of the account hours listed in a direct account. All the account hours listed as indirect are to be excluded from the actual work hours that are submitted to the productivity data system. A decision was made to include rework hours in actual work hours. Rework hours were included because they affect productivity and are important to evaluate productivity performance. It would have been difficult to remove them from work hours because many companies do not track rework hours. Detailed activities or work items for the seven categories are divided into two classes: inclusion and exclusion in Table 2. The following sections provide a discussion of each of the metric categories.

Concrete

Concrete metrics range from slabs and foundations to concrete structures such as beams and columns. Table 3 shows the list of activities for concrete that provides a baseline to compute work hours for concrete work. Inclusion means direct activity and exclusion means indirect activity. This list permits standardized productivity definitions for concrete work. Work hours of the activi-

Table 2. List of Direct and Indirect Accounts

Account		
Direct	Indirect	
Direct craft labor	Accounting	Orientation time
Foreman	Area superintendent	Payroll clerks/timekeepers
General foreman	Assistant project manager	Procurement
Load and haul	Bus drivers	Process equip. maintenance
Operating engineer	Craft planners	Project manager
Safety meetings	Craft superintendent	QA/QC
Scaffolding	Craft training	Quantity surveyors
Truck drivers direct	Crane setup/take down	Receive and offload
	Document control	Recruiting
	Drug testing	Safety
	Equipment coordinator	Safety barricades
	Evacuation time	Security
	Field administration staff	Show-up time
	Field engineer project	Site construction manager
	Field staff (hourly)	Site maintenance
	Field staff (salary)	Subcontract administrator
	Fire watch	Supervision (hourly)
	Flag person	Surveying crews
	General superintendent	Temporary facilities
	Hole watch	Temporary utilities
	Janitorial	Test welders
	Job cleanup	Tool room
	Master mechanic	Truck drivers indirect
	Material control	Warehouse
	Mobilization	Warehousing
	Nomex distribution	Water hauling

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Table 3. List of Activities for Concrete

Inclusion	Exclusion
Loading, hauling to, and unloading material at the jobsite yard	Piling
	Drilled piers
Local layout	Wellpoints and major dewatering
Excavation and backfill	Concrete fireproofing
Fabrication	Batch plants
Stripping and cleaning forms	Nonpermanent roads and facilities
Field installation of reinforcing material	Third party testing
Field installation of all embeds	Mass excavations
All concrete pours, curing, finishing, rubbing, mud mats	Rock excavations
	Site survey
Anchor bolt installation	*Q*-deck
	Sheet piles
	Earthwork shoring
	Cold pour preparation
	Grouting
	Precast tees
	Panels, decks, vaults, manholes, etc.

ties listed on the column labeled "Inclusion" will be summed to compute work hours for each concrete productivity metric.

Slabs are categorized into three types: on-grade, on-deck/elevated slabs, and area paving. Foundations are categorized by size based upon the volume of concrete. Concrete structures are reported as one element that includes columns, beams, cooling basins, trenches, formed elevated slabs/structures, and retaining walls. The concrete productivity metrics are calculated as work hours per cubic yard.

An overall concrete productivity metric includes all measuring elements together in order to present overall productivity for concrete. An overall concrete productivity metric can be achieved because all measuring elements use the same unit (cubic yards) for output. Furthermore each productivity metric in the concrete category can be calculated as a norm and compared within the same subcategory to show the differences for each subcategory of slabs, foundations, and concrete structures.

Table 4. List of Activities for Structural Steel

Inclusion	Exclusion
Shakeout	Fabrication
Transporting	Demolition
Erection	Architectural work such as roofing, siding and vents
Plumbing	
Leveling	
Bolting	
Welding	

Structural Steel

For measurement, structural steel was subcategorized into structural steel, pipe racks and utility bridges, and miscellaneous steel. Structural steel includes trusses, columns, girders, beams, struts, girts, purlins, vertical and horizontal bracing, bolts, and nuts. Pipe racks and utility bridges include steel structures outside of the physical boundaries of a major structure that are used to support pipe, conduit, and cable tray. Miscellaneous steel includes handrails, toeplate, grating, checker plate, stairs, ladders, cages, miscellaneous platforms, premounted ladders and platforms, miscellaneous support steel, T and H type supports, trench covers, and Q-decking.

Table 4 lists major structural steel activities and categorized into two classes: directs to be included and indirects for exclusion. In general, direct activities involved in the installation of structural steel are included, but preparation and support activities such as fabrication and demolition are not included as structural steel work. The activities listed in the "Inclusion" column are included in calculating actual work hours for structural steel work. Based on this list, companies can compute and provide

Table 5. Elements of Electrical Work

Element	Components
Panels and small devices	Lighting and power panels, dry type transformers, control stations (pushbuttons, small local panels, etc.), welding receptacles, and their supports.
Electrical equipment	Transformers, switchgear, uninterrupted power supply systems, motor-control centers , distributed control system/programmable logic control racks, and panels, etc.
Exposed or aboveground conduit	Conduit, hangers, supports, fittings, flexible connections, marking, grounding jumpers, seals, boxes, etc. Excludes lighting conduit.
Underground, duct bank or embedded conduit	Conduit, supports, grounding jumpers, etc. Excludes excavation, backfill, concrete, manholes, etc.
Cable tray	Tray, channel, supports, covers, grounding jumpers, marking, etc. Excludes fire stop or cable tray for instrument wire and cable.
Power and control cable (600 V and below)	600 V and below power and control cable. Excludes heat-tracing cable.
Power cable (5 and 15 KV)	Medium voltage power cables.
Lighting	Fixtures (including lamps and supports) and conduit and wiring from the lighting panel to the fixtures. Any control equipment, switches, conduit, wiring, and accessories installed on the load side of the lighting panel. Lighting panels are included in panels and small devices and power feeder wing for the panel are included in power and control cable-600 V.
Grounding	Cable, ground rods, connectors and all accessories for the installation of the plant ground grid. Ground cables pulled into cable trays, duct banks, and installed exposed in electric or other rooms.
Electrical heat tracing	Electric heat trace cable, power feeds to the cable, control accessories, end of line devices, connectors, tape or other strapping/support materials, and any other items needed to complete the heat trace system.

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Table 6. List of Activities for Piping

Inclusion	Exclusion
Erecting and installing piping including welding	Nondestructive evaluation
	Steam tracing
Valves	Stress relieving
In-line specials	Underground piping
Flushing/hydro testing	Offloading pipe as it is received
Tie-ins excluding hot taps	Commissioning
Material handling	Field fabrication
In-line devices, hangers and supports	
Equipment operators	

Table 7. List of Activities for Instrumentation

Inclusion	Exclusion
Installation, calibration, testing, check out, and field certification of the devices	Distributed control system equipment
Process tubing	Software
Instrument air tubing	Installation of in-line devices
Cable trays	Programming and configuration
Conduits	
Instrument wire and cable	
Junction boxes	

work hours for structural steel work. The output of structural steel is measured in tons and the unit of productivity metrics is hours/ton.

Electrical

The electrical productivity metrics are computed based on the installed quantity of each electrical element and work hours of electrical activities including the selected activities such as installation, testing, and labeling for the components defined for each measuring element. The electrical components for each electrical measuring element were defined and these are listed in Table 5.

The electrical productivity metrics surveyed include five subcategories and 11 measuring elements. Subcategories are as follows: (1) electrical equipment and devices, (2) conduit, (3) cable tray, (4) wire and cable, and (5) other electrical metrics. Quantities of electrical equipment, devices, and lighting fixtures are counted in numbers installed and quantities of the other metrics such as conduit and cable and are measured in linear feet.

Piping

Piping is an important component of industrial projects. This construction productivity metrics effort focused on industrial projects, so piping is one of the seven categories in the metrics system.

The piping category is divided into three subcategories: small bore, inside battery limits (ISBLs) large bore, and outside battery limits (OSBLs) large bore. Each subcategory is further divided into four measuring elements based on the pipe material to include carbon steel, stainless steel, chrome, and other alloys.

Small bore is defined as pipe with a diameter less than or equal to $2\frac{1}{2}$ in. Large bore is defined as pipe with a diameter equal to and greater than 3 in. Large bore pipe is further divided into two groups: ISBL and OSBL because there is a perception that productivity of an ISBL large bore is worse than an OSBL large bore due to limited workspace and its connection with equipment. The battery limit is a geographic boundary that defines the manufacturing area of the plant that houses process equipment, but it does not include auxiliary and service buildings or offsite facilities. Therefore, the ISBL large bore is pipe that is installed in the main

Table 8. Elements of Equipment Metrics

Element	Components
Pressure vessels	This includes tray/packed towers, columns, reactors/regenerators, and other miscellaneous pressure vessels. Field fabricated towers, columns, reactors, and regenerators are not to be included.
Atmospheric tanks (shop fabricated)	This includes storage tanks, floating roof tanks, bins/hoppers/silos/ cyclones, cryogenic and low temperature tanks and other miscellaneous atmospheric tanks. It includes shop built-up and field-erected tanks. However, this does not include field fabricated and assembled tanks.
Atmospheric tanks (field fabricated)	This includes storage tanks, floating roof tanks, bins/hoppers/silos/cyclones, cryogenic and low temperature tanks, and other miscellaneous atmospheric tanks.
Heat transfer equipment	This includes heat exchangers, fin fan coolers, evaporators, package cooling towers and miscellaneous other heat transfer equipment.
Boiler and fired heaters	This includes packaged boilers, field erected boilers, fired heaters, waste heat boilers, stand-alone stacks, and miscellaneous other boilers and fired heaters.
Rotating equipment (w/drivers)	This includes compressors (centrifugal/reciprocating), blowers, screw rotary compressors, metering/in-line pumps, pumps (centrifugal/ reciprocating), positive displacement pumps, agitators, mixers, blenders and other miscellaneous compressors, fans and pumps.
Material handling equipment (w/drivers)	This includes conveyors (belt, chain, screen, rotor, etc.), cranes and hoists, scales, lifts, stackers, reclaimers, ship loaders, compactors, feeders and baggers, and miscellaneous other material handling equipment.
Power generation equipment	This includes gas turbines, steam turbines, diesel generators, and other miscellaneous power generation equipment
Pulp and paper equipment	This includes all paper machines and other miscellaneous pulp and paper equipment.
Other process equipment	This includes specialty gas equipment, bulk chemical equipment, process equipment, particle extraction (bag houses, scrubbers, etc.), treatment systems (water treatment, etc.), incinerators, and flares/flare systems.
Modules and preassembled skids	This includes modules (partial units) and complete skids units.

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process facility and the OSBL large bore represents pipe that is installed outside of the main facility to connect main process equipment with offsite facilities or auxiliary buildings. Examples of offsite facilities include steam boilers, electrical power generators, cooling towers, and fuel supply systems. Auxiliary buildings include administrative offices, laboratories, maintenance shops, warehouses, and others. A detailed listing of activities to be included to compute the actual work hours for piping construction productivity metrics is shown in Table 6. Work hours for each piping productivity metric can be calculated in the same manner as described earlier.

An overall piping productivity metric can be calculated because all piping metrics use the same output unit: linear feet of pipe. Overall productivity metrics for three subcategories can also be calculated to present high-level base measurements.

Instrumentation

Generally, instrumentation includes sensors, controllers, and transmitters between sensors and controllers (Sandler and Luckiewicz 1987). In this study, the instrumentation category has three measuring elements: instrumentation loops, devices, and instrumentation wire and cable. Table 7 lists the activities and components that should be included and excluded in determining actual work hours.

Loops and devices productivity are measured in work hours for each unit installed. Instrumentation wire and cable is measured in hours per linear feet.

Table 9. List of Activities for Equipment Insulation

Equipment inclusion	Piping inclusion
Installation of insulation	Installation of insulation
Jacketing overall vessels, tanks, exchangers, etc.	Jacketing over pipe, valves and fittings
Installation of equipment blankets for pumps, exchangers, etc.	Installation of valve insulation blankets and flange insulation
Material handling	

Table 10. Construction Productivity Metrics

Metrics	Unit	Metrics	Unit
Concrete		ISBL large bore (3 in. and larger)	
Slabs		Carbon steel	h/ft
On-grade	h/yd^3	Stainless steel	h/ft
Elevated slabs	h/yd^3	Chrome	h/ft
Ares paving	h/yd^3	Other alloys	h/ft
Foundation		OSBL large bore (3 in. and larger)	
<5 yd^3	h/yd^3	Carbon steel	h/ft
5–20 yd^3	h/yd^3	Stainless steel	h/ft
21–50 yd^3	h/yd^3	Chrome	h/ft
>50 yd^3	h/yd^3	Other alloys	h/ft
Concrete structure	h/yd^3	Instrumentation	
Structural steel		Loops	h/EA
Structural steel	h/t	Devices	h/EA
Pipe racks and utility bridges	h/t	Instrumentation cable	h/ft
Miscellaneous steel	h/t	Equipment	
Electrical		Pressure vessels	h/EA
Electrical equipment and devices		Atmospheric tanks (shop)	h/EA
Panels and small devices	h/EA	Atmospheric tanks (field)	h/EA
Electrical equip. 600 V and below	h/EA	Heat transfer equipment	h/EA
Electrical equip. over 600 V	h/EA	Boiler and fired heaters	h/EA
Conduit		Rotating equipment	h/EA
Exposed or above ground	h/ft	Material handling equipment	h/EA
Underground or embedded	h/ft	Power generation equipment	h/EA
Cable tray	h/ft	Pulp and paper equipment	
Wire and cable		Woodyard equipment	h/EA
Power and control cable: 600 V	h/ft	Pulp mill equipment	h/EA
Power cable: 5 and 15 KV	h/ft	Bleach plant equipment	h/EA
Other electrical		Stock preparation equipment	h/EA
Lighting	h/EA	Wet end equipment	h/EA
Grounding	h/ft	Dryer sections	h/EA
Electrical heat tracing	h/ft	Dry end equipment	h/EA
Piping		Other process equipment	h/EA
Small bore (2-$\frac{1}{2}$ in. and smaller)		Modules and preassembled skids	h/EA
Carbon steel	h/ft	Insulation	
Stainless steel	h/ft	Equipment insulation	h/ft^2
Chrome	h/ft	Piping insulation	h/ft
Other alloys	h/ft		

Note: EA=each.

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Equipment

Equipment is a major part of industrial projects. Piping, instrumentation, and insulation are installed to connect, control, and insulate equipment. In the process industry, equipment often is somewhat simple, but the installation of equipment, piping, insulation, and instrumentation takes more time. Equipment in a paper mill however, is quite different from typical industrial projects, and thus pulp and paper equipment is separately grouped in this category. The equipment items that are included for equipment productivity metrics are detailed in Table 8.

All equipment metrics are calculated in hours/each. The size of equipment may differentiate the productivity rate, however, the total weight or capacity of the equipment is surveyed to establish the relationship between the equipment size and productivity.

Insulation

In the process industry, it is important to reduce heat losses during transfer between process equipment and piping. Insulating materials are used between process equipment, piping, and their surroundings to reduce heat losses and gains (Sandler and Luckiewicz 1987). Insulation productivity metrics are divided into two groups: equipment insulation and piping insulation. Table 9 shows the activities that should be included for equipment insulation and piping insulation.

Table 10 illustrates all construction productivity metrics for seven categories and corresponding units.

Preliminary Analysis

At the time of preparation of this paper, data have been collected on 16 industrial projects using the definitions provided. Preliminary analysis was performed to assess whether meaningful metrics could be calculated from the data and to establish an analysis format for further study. Based on the results of preliminary analysis, developed construction productivity metrics can be considered as an effective tool to collect standard construction productivity data to provide meaningful information for benchmarking and productivity research analysis.

Conclusion

The most important contribution of this reseaerch is development of standard metric definitions for construction productivity. As has been described previously, CII and other researchers have performed research on productivity in construction. A few previous efforts aimed to establish baseline productivity, but there have been few followup studies. Establishment of a construction productivity data collection tool with a common set of definitions is the contribution of this research.

A significant amount of positive feedback from industry experts has been received through subsequent workshops. The construction productivity metrics developed by this research effort will provide baseline productivity and a basis for continuous construction productivity improvement through benchmarking.

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