CONSTRUCTION INDUSTRY INSTITUTE

Determinants of Craft Labor Productivity

Research Summary 143-1

Construction Industry Institute

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Craft Labor Productivity

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Executive Summary

Construction craft productivity improvement can be achieved in multitude ways. Which are best? Construction Industry Institute (CII) Research Team 143 searched for a solution to this complex subject.

This research summary describes a study by CII that compares two strategies for improving construction labor productivity. One strategy, the buffer strategy, stresses the importance of providing large stockpiles (buffers) of design, material, and construction equipment to craft workers. Large buffers provide flexibility to a production system by allowing worker to shift from one task to another when material shortages, design defects, or other impediments are encountered. The second strategy, the production planning strategy, provides effective craft production by ensuring that all necessary productive resources are available for craft workers. The production planning strategy encompasses all jobsite activities that directly support craft labor. Production planning is the domain of project material expeditors, field planners, and field engineers who ensure that craft workers have the materials and information needed for production activities. Production planning is the bridge between project planning and actual construction work.

Most construction firms use both strategies on their jobsites. However, increased use of buffers (e.g., larger stockpiles of materials, design and equipment) reduces the need to plan production in detail by introducing flexibility into the production system. Conversely, precise production planning reduces the need for large buffers by ensuring that the correct materials, designs, and equipment are available for craft workers.

This publication offers readers a chance to compare these two strategies for productivity improvement. Both techniques have advantages and disadvantages. The ultimate goal is to choose the strategy that improves craft productivity and leads to successful project planning, execution, and start-up.

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Introduction

Field labor continues to be one of the largest costs and most significant variables in a construction project. CII Research Team 143, Craft Productivity Improvement, was initially chartered to "identify craft productivity improvement methods and to reliably and authoritatively evaluate the impact of these ideas on actual job site productivity." RT 143 investigated the effectiveness of using earlier acquisition of project resources and increased production planning as a way to improve jobsite productivity. In particular, the effect of actions — providing design information and construction materials earlier in the construction process and providing more construction equipment and non-manual worker support to the work crews — was studied.

Productivity History

There is widespread agreement on the need to improve productivity as cited in the original Construction Industry Cost Effectiveness (CICE) reports by The Business Roundtable. Much has been accomplished since then through implementation of CII's "Best Practices," which clearly have reduced project costs. Has actual labor productivity in terms of output per work-hour changed?

Construction industry labor productivity changes in the last 20–30 years remain controversial and subject to strongly held opinions. Little absolute data are available due to the uniqueness and proprietary nature of each project. The Center for Construction Industry Studies Report No. 7, *U.S. Construction Labor Productivity Trends 1970-1998*, shows an increase in productivity, measured as output/dollar, due primarily to depressed real wages, but also to technological advances in its sampling of six representative tasks.

The Bureau of Labor Statistics maintains productivity indices for all significant sectors of the economy except for the construction sector due to lack of suitable data. Other government data show greater than 50 percent productivity increases for U.S. manufacturing and mining industries in terms of worker output. A 16 percent decline, however, is seen in construction industry worker productivity.

Research Basis

Construction labor productivity is not increasing at a rate commensurate with increases in the rest of the economy. What can be done to improve field labor productivity? A conventional approach to improve productivity is to provide large stockpiles of engineering design, materials, and construction equipment. This strategy improves labor productivity by providing multiple alternative work tasks and assignments. If one work task is unavailable due to material shortages, changes or other impacts, other work assignments can be made. In this research, an approach that relies on large stockpiles of production resources is referred to as the "buffer strategy."

Another means to improve labor productivity is to invest more heavily in persons who support the production workers. Field expeditors, field engineers, and field planners can ensure that all necessary productive resources are purchased and available for the craft workers. This is called the "production planning strategy." Production planning encompasses all jobsite activities that directly support craft labor. Production planning is not pre-project planning nor is it project scheduling. Production planning is the domain of non-manual field staff who ensure that craft workers have the materials and information needed for production activities.

This research compared the effectiveness of these two strategies. The strategies are complementary: increased use of buffers (e.g., larger stockpiles of materials, design and equipment) reduces the need for detailed production planning by introducing flexibility to the production system. On the other hand, precise production planning reduces the need for large buffers by ensuring that the correct materials, designs, and equipment are available for the craft worker. So the question is, "Should one pay for increased buffers or should one pay for increased production planning?"

To answer this question, the research team focused on piping and electrical crafts for industrial construction projects. In industrial construction projects, piping and electrical crafts usually consume the most field labor hours and are on the schedule critical path. RT 143 measured the effect on worker productivity for these two crafts as a function of four factors:

1. Relative availability of engineering design (design buffer)

2. Relative availability of the right materials to be installed (material buffer)

3. Amount of construction equipment to support that craft/crew's work (equipment buffer)

4. Relative availability of non-supervisory construction support personnel including field engineers, planners, and expeditors (production planning buffer)

These four elements are important in providing craft workers with the resources necessary for efficient production. Many factors affect jobsite labor productivity, however. A comprehensive list of factors that affect labor productivity is shown in Table 1 (next page). As one might expect, jobsite labor productivity varies greatly depending upon such elements as design quality, worker skill, and project location. To the extent possible, these were controlled in the research.

Table 1. Factors That Could Affect Craft Worker Productivity

ENGINEERING/DESIGN	CONSTRUCTION MANAGEMENT
Design/drawing availability	Constructability reviews
Design quality — errors & omissions	Construction techniques
Changes	Contractor staff organization
PROJECT/SITE CONDITIONS	Production support resources
Weather	Owner organization
Proximity to operating area	Contracting strategy
Site rules (safety requirements, no smoking)	Craft coordination (workflow)
Unique owner requirements	Subcontractor coordination
Plant construction permits	Adherence to execution plan
Local codes and government inspections	Supervision skills
Size of project	Construction equipment & tools (availability & quality)
Project execution strategy	Manning levels
Project complexity	**LABOR**
Worker density	Labor market
New process technology	Skill levels
Proximity of laydown area	Craft flexibility
Existing obstructions	Learning curves
Unknown underground conditions	Overall work force culture
Confined space entry	Worker motivation
Scaffolding	Worker compensation and incentives
QA/QC requirements	Work schedule (4-10's, 5-8's, etc.)
MATERIALS	Overtime (scheduled and unscheduled)
Engineered equipment availability	Shift work
Timing for bulk materials	Rework
Material control of items on site	
Quality of materials	

Data Collection

Data were collected from 26 industrial projects (see Figure 1) in the United States, totaling 1307 crew days of work for both piping and electrical crafts. To the extent practical, data were collected from each project at three stages of completion, 25, 50, and 75 percent complete, avoiding the beginning and end of the work, when productivity usually is lower. Projects ranged in size from $830,000 to $244,000,000 and included grass roots and retrofit installations. Eighty percent of the projects were executed at open shop sites and 20 percent at union sites.

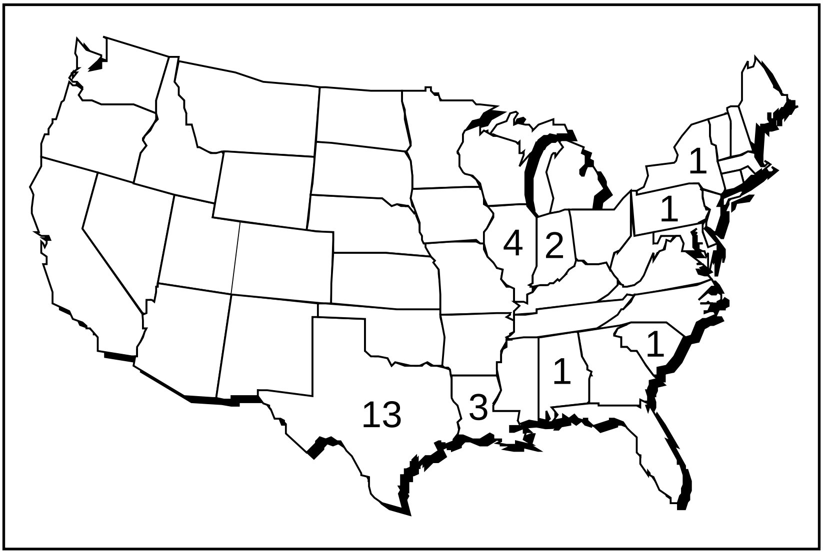

Figure 1. Geographic Distribution of Projects in the Study

Adjustment of Measured Productivity Index

Evaluation of the effects of design, material, equipment and production planning on craft labor productivity required development of a productivity measurement standard. Since the surveys gathered data across multiple jobsites, a Standard Productivity Index (PI) was calculated as follows:

$$\text{Standard Productivity Index (PI)} = \frac{\text{Worker Hours Reported}}{\text{Standard Worker Hours}}$$

The PI compares the actual time required by each work crew to a standard amount of time, required by a typical work crew, to complete the same amount of work. Worker Hours Reported were determined from the hours recorded on the survey forms for each crew. Standard Worker Hours were estimated using historical data from the industry. Standard Worker Hours for piping work came from the MCA Manual (MCA 1998) and for electrical work; they came from the NECA Manual of Labor Units (NECA 1997). Before computing the PI, Worker Hours Reported and Standard Worker Hours were summed for an entire week for each crew, at each jobsite, for each reporting period. The summarized weekly values were used to compute weekly PIs for each crew at each jobsite. The daily crew data were summarized by the week to avoid the large variations typically seen in daily productivity values.

The following definitions were used to indicate craft productivity performance:

$$\text{PI} = \begin{cases} < 1.0 & \approx \text{ better than expected productivity} \\ 1.0 & \approx \text{ expected productivity} \\ > 1.0 & \approx \text{ worse than expected productivity} \end{cases}$$

Computed as shown above, the PI values reflect the effects of both project-specific and management-controlled productivity factors. For example, jobsites in the U.S. Gulf Coast and the Northeast U.S. need to be distinguished from one another due to their inherently different labor climates. Likewise green-field projects need to be distinguished from retrofit projects. To control for these and other project-specific productivity effects, the PI was adjusted using regression techniques. From the regression analysis, five factors were determined to be significant and were subsequently adjusted for in the study. The five factors were:

- project location
- project type (grass roots or retrofit)
- project delivery system (EPC, EPCM, Separate Design, and Constructor)
- labor source (union or non-union)
- total craft work-hours.

After appropriate adjustments, the PI became the Adjusted Productivity Index (API) that was used in all subsequent analyses.

Measurement of Jobsite Buffers

Design buffers are a function of both time and quantity of work complete. As more design is completed before construction commences, the design buffer becomes larger. In traditional thinking, large design buffers improve productivity by allowing earlier fabrication or delivery of material. Also, relatively early design provides the opportunity to discover errors in design documents. The calculation used for the design buffer is shown below:

$$\text{Design Buffer} = \frac{\text{Percentage of Design Completed}}{\text{Percentage of Craft Work Completed}}$$

Various measures for both design complete and craft work complete were evaluated. For piping work, it was determined that comparing Isometric Design Complete vs. Spools Installed would be used for calculating the design buffer. For electrical work, Power Plans Complete vs. Cable Installed was the method used for calculating the design buffer.

Material buffers are tightly coupled to design buffers because design activities must precede material procurement and delivery. Material buffers were calculated as the ratio of material received to work completed, as shown below:

$$\text{Material Buffer} = \frac{\text{Percentage of Material Received}}{\text{Percentage of Craft Work Completed}}$$

As with the design buffers, various measures for both materials received and craft work complete were evaluated. The analysis determined that the ratio of Spools Received to Spools Installed was the most effective way to calculate the material buffer for piping, and the ratio of Cable Received to Cable Installed was most effective for electrical work.

Equipment buffers were calculated in a way that evaluated the rental value of equipment on-site using standard equipment rental rates as published in the Associated Equipment Distributors yearly "Rental Rates and Specifications" guide. The total equipment rental value was calculated for each craft (e.g., all pipefitters) and by crew and worker. To normalize the value of equipment for the difference in project size and work force size, two alternative measures for equipment buffers were developed:

$$\text{Equipment Buffer (per worker)} = \frac{\text{Total Value of Equipment On-site}}{\text{Number of Workers On-site}}$$

$$\text{Equipment Buffer (per crew)} = \frac{\text{Total Value of Equipment On-site}}{\text{Number of Craft Crews On-site}}$$

Ultimately, the value of equipment on site per worker was the most effective measure for both piping and electrical work.

Production planning support levels are similar to equipment buffers in that there is no standard method to calculate them. Multiple potential measures for planning levels were evaluated by developing ratios of the number of persons assigned to directly support the work of the field crews. By our definition, field engineers, expeditors and field planners were all judged to be "field support." Alternatively, safety personnel, QA/QC and office staffs were not included in the measure of field support. Superintendents and foremen, at all levels, were classified as "field supervision" and were not included in this measure. The amount of planning support was calculated as the ratio of non-craft field support workers to the number of craft workers or the number of crews, as shown below:

$$\text{Planning Support} = \frac{\text{Number of Field Support Persons On-site}}{\text{Number of Craft Crews or Workers On-site}}$$

Ultimately, it was determined that the ratio of field, non-craft support personnel per worker was the most effective measure of planning support in both the piping and electrical crafts. This measure does not consider the efficiency or methods of field support personnel, only their overall numbers per worker or craft.

Using standard statistical techniques, the research team evaluated how differences in design, materials and construction equipment buffers affected API, i.e., the buffer strategy. RT 143 also evaluated how relatively more production planning resources affected API, i.e., the production planning strategy. Finally, the team evaluated (in order of magnitude terms) the relative cost effectiveness of the buffer strategy and the production planning strategy.

2

Findings

Planning Resources Really Pay Off

This research focused on the field planning functions that include such activities as communication between site management and crafts, look-ahead planning, material/equipment coordination on site, and other related activities. Planning resources appear to pay off by allowing piping and electrical work crews to have the proper amounts of materials, equipment, design, and work sequencing plans that are essential for the crafts to perform their work efficiently. Over the course of the research project, team members interviewed craft supervision including foremen and requested their input on the factors they felt positively improved craft productivity. Comments consistently related to planning: “Work the plan,” “Understand the plan,” and “Communicate the plan” were typical. The numerical results clearly indicate the value of production planning in improving labor productivity. The work force also believes planning has positive results based on personal experiences in the industry.

Piping Craft

The use of increased planning support in the piping craft was effective in improving piping productivity, as shown in Figure 2.

Productivity improved significantly as the number of field support personnel per worker was increased. Average contractor in this study employed one support worker for every 30 craft workers and achieved an API of about 1.05. Contractor API ranged from 1.1 to an absolute low of 0.7, when the numbers of field support personnel increased from no planning support personnel to a high of one support person for every five craft workers. Compared to the typical contractor, the improvement in piping productivity was significant as the number of planning support personnel increased.

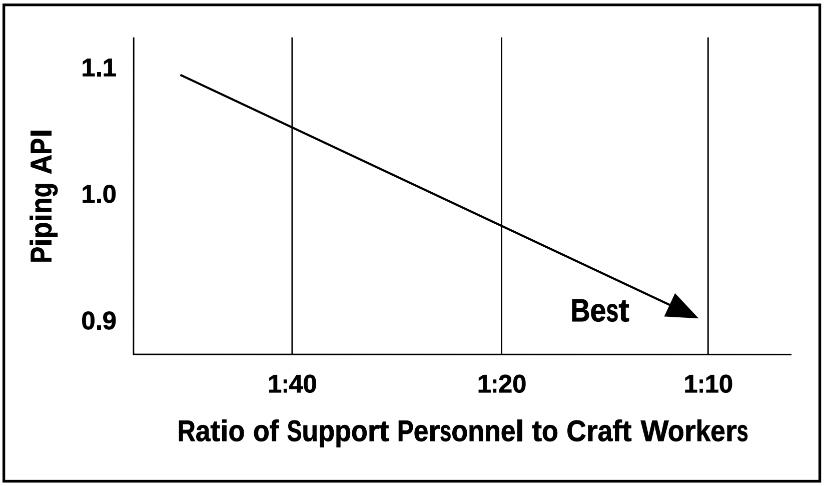

Figure 2. The Best Sites Had One Support Person for 10 or Fewer Craft Workers

Contractors that employed one planning support person for every 10 craft workers showed an average productivity improvement of 20 percent.

Electrical Craft

The use of increased planning support showed good performance in improving electrical labor productivity as well. The typical contractor in this study used one planner for every 45 electricians and achieved an API of 1.05. In instances where there were no field support personnel on-site, the adjusted productivity value was 1.09. As the amount of field support personnel increased towards one field support personnel per 10 workers, the new adjusted productivity value was 0.95. These results indicate the significant effect that production support staff has on labor productivity.

These findings provide strong support for special emphasis to be placed on production planning when owners and contractors are preparing to execute a project. However, the research found many project executives believe large buffers of materials and equipment are essential to provide flexibility and continuity during construction. For this reason, the team also evaluated the effect of buffers on labor productivity.

Buffers (Stockpiles) Improve Piping Productivity

Piping Design Buffers

Increases in piping design availability were effective in improving productivity. The fundamental measure of piping design buffers was the ratio of isometric drawings received (expressed as percent of the total number of piping isometric drawings) to piping installed (percent of the total number of spools). The average contractor in this study employed a design buffer in the range of 1 to about 1.5 (average ≈1.2) and achieved an API of 1.05. Comparing projects where the design buffer was approximately 1 to projects where the buffer approached 3, productivity increased about 15 percent as illustrated in Figure 3. These results, which are referred

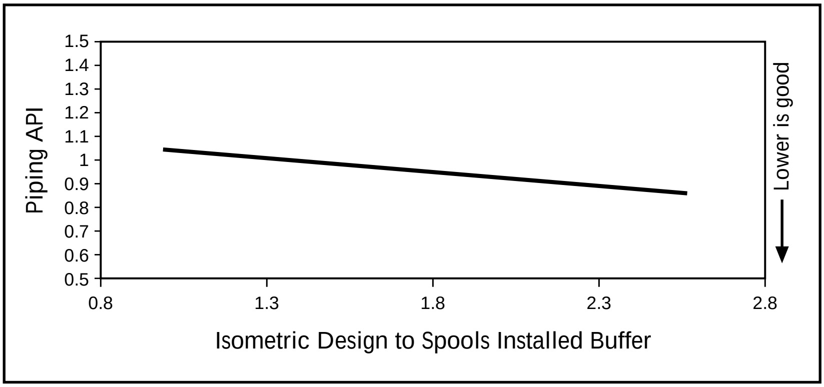

Figure 3. Piping Design Buffer — Productivity Improvement

to as the "buffer strategy," are significant since piping is often the critical path of chemical process industry projects and it is not easy to complete piping design early in the project life. An equally significant finding is that those jobsites that maintained a large piping design buffer experienced much more predictable crew performance. That is, the API values were much more stable on projects with large design buffers, indicating that design buffers enable better and more consistent crew production.

Piping Material Buffers

The ratio of pipe spools received to pipe spools installed is the piping material buffer. Increased material buffers also improved piping productivity as shown in Figure 4.

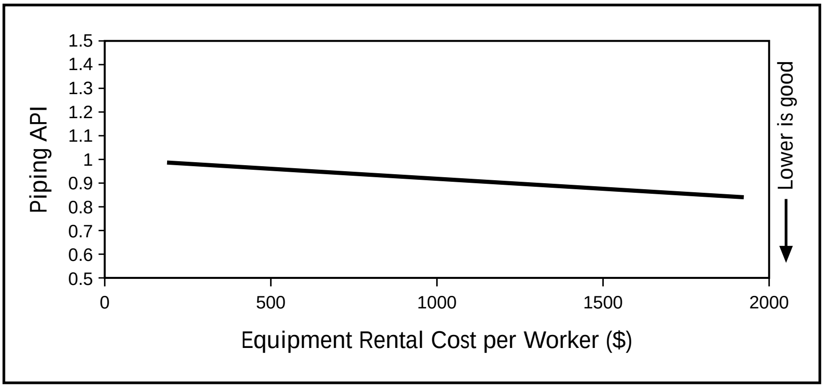

Figure 4. Piping Material Buffer — Productivity Improvement

The average contractor maintained a pipe spool material buffer of about 1.25 and achieved an API of ≈1.05. Again, when a project material buffer approaches 1.0, spools received equal spools erected, and the project is working in a just-in-time delivery mode. As this ratio increases to 3.0 the API shows a 12 percent improvement in productivity. These findings are consistent with CII's earlier research, "Managing Uncertainty in the Piping Function." There, high performance resulted when at least 60 percent of the pipe had been received when 20 percent had been installed. Large piping stockpiles provide alternative work activities if a crew's planned work is delayed for any reason. As with design buffers, the variation in API values decreases significantly with increasing buffer size. This is more evidence of the stability produced by materials buffers in jobsite production systems.

Piping Construction Equipment Buffer

The construction equipment buffer was measured as equivalent rental value of construction equipment per craft worker. Field input apportioned shared equipment among different crafts and several crews in the same craft. For example, project cranes may be shared among several crafts. All piping crews may share trucks, personnel lifts, and similar equipment, whereas welding machines may be assigned to a single crew. Increased availability of construction equipment for piping activities results in improved productivity as shown in Figure 5. Productivity gradually improved as the amount

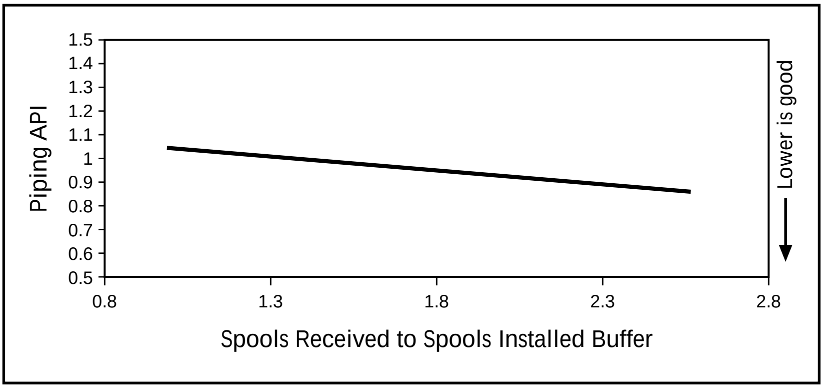

Figure 5. Piping Equipment Buffer — Productivity Improvement

of rental equipment per worker increased from $200 of rental equipment per worker (API = 1.0) to $1,800 of rental equipment per worker (API = 0.85). This was an average 15 percent difference in productivity between the least well-equipped projects and the best-equipped projects. However, these results were not as uniform as the results for design and material buffers. Increases in piping construction equipment buffers also did not lead to the same degree of stability in API.

At any given buffer size, RT 143 observed a wide variation in jobsite API. No doubt, these variations are due to unadjusted jobsite differences in design quality, constructability, and worker skill.

However, for any given buffer level, there was an unassailable trend toward improved crew performance with increasing buffer size. It is also worthwhile to reiterate that in the cases of design, material and (less definitively for) planning as the buffer size increased, the API values varied much less from jobsite to jobsite, indicating less volatility in productivity performance. Thus, not only did labor productivity improve with increased resource availability, but the ability to predict productivity levels improved as well. Reduced labor performance volatility is an unexpected benefit to large design, material, and equipment buffers.

Different Results for Electrical Productivity

The research data indicate that the “buffer strategy” does not support improvements in electrical craft productivity. For practical purposes, the buffers have no discernable impact on electrical labor productivity. Productivity appeared to be unaffected by increasing electrical design buffers. The difference in productivity values between a buffer ratio of 1.00 and 5.00 was essentially zero. To a large extent electrical work bypasses the shop detail and fabrication phase. Electricians can begin their installations immediately on issuance of released for construction drawings. Therefore, they do not need large “stockpiles” of design as a precursor to fabrication to be highly productive. Electricians also have much more flexibility in arranging conduit and sometimes tray, and typically route their cable conductors after the process piping has been installed.

The use of increased material buffers in the electrical craft likewise showed no influence in improving labor productivity. The difference in productivity values between a buffer ratio of 1.0 and 3.0 was only 0.40 percent. The team hypothesizes this is because electrical work uses a significantly higher percentage of readily available bulk materials than does piping erection. These materials do not require prefabrication, but normally are stock materials “off the shelf.”

Likewise, the use of increased equipment buffers in the electrical craft showed no results in improving productivity. Similar to the electrical design and material buffers, the construction equipment buffer did not prove to be a powerful predictor of productivity performance.

The Economics of a Project Buffer Strategy

The research was extended to consider the economic ramifications of the buffer strategy. Specifically, the team attempted to answer the question "Should a project invest in increased buffers?" This analysis was limited to the piping craft only because results for electrical buffers produced minimal productivity improvements.

A "buffered" project incurs added costs associated with holding and managing increased jobsite inventories. There are also costs associated with furnishing design at an earlier point in the project. Offsetting these increased costs on a buffered project are the labor cost savings attributed to improved productivity caused by the larger design and material buffers. On the other hand, a non-buffered project has lower inventory and handling costs but it does not obtain the benefits of improved labor productivity.

In the (order-of-magnitude) analysis for a $25,000,000 project, these net cost differences for a non-buffered project were quite small (see Table 2). That is, the savings in inventory costs were cancelled by the unrealized labor productivity savings. On the other hand, a highly buffered project incurred extra inventory and design costs (≈$120,000) that were not wholly offset by improved labor productivity.

Table 2. Additional Research Finding: Design and Material Stockpile Costs Outweigh Comparative Labor Savings

Cost Element	**Non-Buffered Project**	**Stockpiled or Buffered Project**
Carrying Cost	$5,000	$44,000
Warehouse Staffing	7,000	0
Design Inefficiencies	$0	15,000
Extra Handling of Materials	(12,000)	0
Laydown Area, Warehousing & Security	(11,000)	18,000
Changes/Refabrication/Field Errors	(20,000)	40,000
Material Waste	(11,000)	30,000
Total Costs or (Savings)	**($42,000)**	**$147,000**
Labor Costs or (Savings)	**$30,000**	**($26,000)**
Cost Differential for $25MM Project	**($12,000)**	**$121.000**

In other words, RT 143 draws the following conclusions regarding the economic effects of large buffers:

1. Large design and material buffers result in labor savings as productivity improves.
2. Large material buffers have hidden costs due to warehousing, security, extra material handling costs, and possibly interest expense.
3. The costs of the buffers outweigh the benefits of labor savings (although these differences are relatively small compared to a $25MM project).

However, it is important to remember that large buffers also serve to stabilize labor productivity performance. In this light, a relatively small investment in project buffers ($120,000 in this case) serves as labor productivity insurance by making crew performance more predicable.

Schedule Ramifications of a Buffer Strategy

There are important schedule implications of the buffer strategy. Consider Figure 6, an S-curve diagram that illustrates the relationship between the design schedule, the material delivery schedule, and the construction schedule for a highly-buffered project.

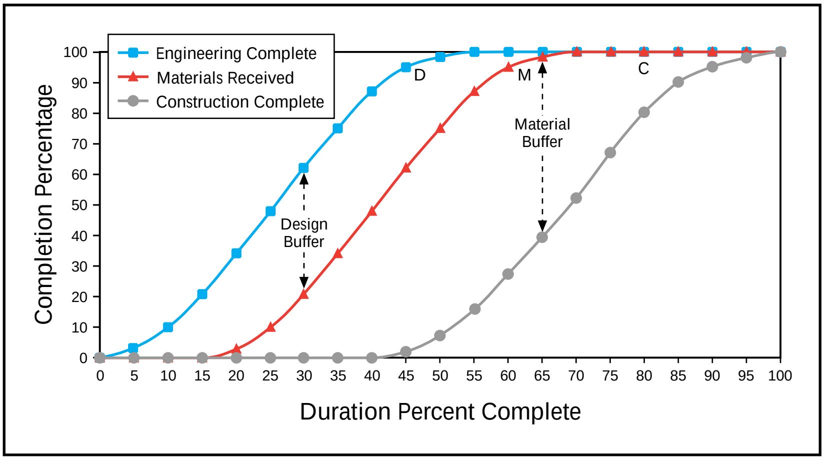

Figure 6. Buffered Project S-Curves

The large distance between the design and materials delivery curve represents a large design buffers. Likewise, the large distance between the materials delivery curve and the construction curve represents a large material buffer. Compare the buffer size implied by Figure 6 to those implied on the non-buffered project shown in Figure 7.

This non-buffered projects must depend on increased planning to prioritize design and material delivery to support field erection

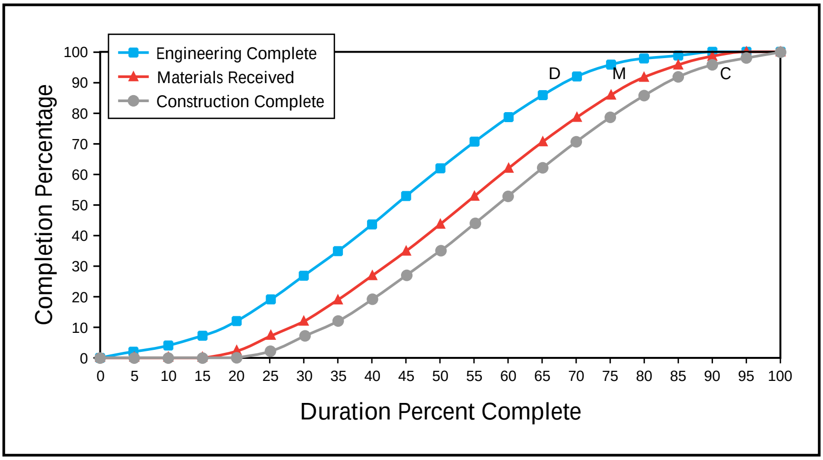

Figure 7. Non-Buffered Project S-Curves

schedules. Notice that the overall rates at which design, material procurement and construction are accomplished are much lower than in a buffered project with a comparable schedule.

What would happen if a project team could reduce project buffers and still maintain the production rates for design, procurement and construction of a buffered project? Such a project is depicted in Figure 8 that we call an expedited project.

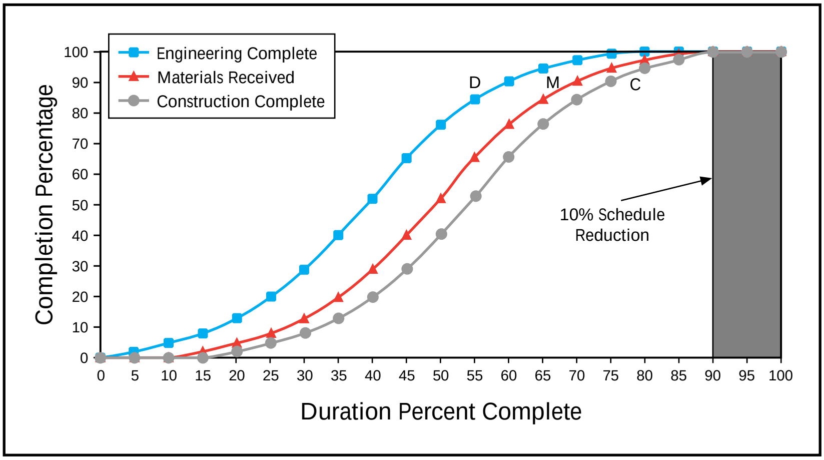

Figure 8. Non-Buffered Expedited Project S-Curves

This scenario uses the accelerated design and material delivery rates of the buffered project, while maintaining the short lead times of the non-buffered project by heavily relying on production planning to provide field coordination. The result is an approximate 10 percent reduction in project schedule. While the team did not develop this project format in detail, it finds these results intriguing in this era of ever-shortening schedules.

3

Conclusions

Comparison of Buffer and Production Planning Strategies

This research reveals distinct differences between the piping and electrical crafts, in terms of efficacy of buffers to improve craft productivity. These findings result from the many differences between these two trades. The piping craft is typically a critical path item and material deliveries are very sensitive to design schedules and shop prefabrication. On the other hand, electrical work is typically not a critical path item until late in the project, many electrical materials do not require prefabrication, and many of its bulk material items are available with short lead-times. Consequently, piping work productivity showed an increased sensitivity to variability in the level of production resources when compared to electrical work productivity. Shielding production for piping crafts is important, since late piping material delivery (or late design that results in late material delivery) causes inefficiency, crew dislocation, and work-around procedures. On the other hand, increased expediting can often diminish the effect of late material delivery for the electrical crafts. In fact, many of the projects in this study established innovative relationships with electrical suppliers that located electrical material warehouses on the project work site.

Both electrical and piping work productivity was extremely sensitive to changes in the degree of planning and production support available for the work crews. The implication is that shielding production through planning efforts improved the flow of work by either avoiding late or missing resources or providing increased expediting and logistic support to overcome late or missing resources.

In summary, for piping activities the conventional wisdom that large buffers are useful improve productivity proved true. Relatively larger stockpiles of design, piping materials, or construction equipment all resulted in higher crew productivity for piping. Larger buffers also improved the stability of crew performance. However, the buffer strategy for electrical work did not appear to affect productivity. The production planning strategy proved more effective than buffers at improving crew productivity. In addition, it was effective for both piping and electrical trades. For many years the leaders in the construction industry have been touting the benefits of project front-end planning. This study shows the benefits of production planning in improving construction site productivity.

Commercial Building and Infrastructure Ramifications

Although this research was based upon industrial construction, its findings can be transferred to other construction markets by identifying project similarities. Piping work is less critical in typical commercial building or infrastructure projects compared to process construction. However, most construction projects have several examples of materials that are also highly dependent on unique design and prefabrication. For instance, structural steel, engineered building skin, and pre-cast concrete elements are all examples of design-dependent, long lead-time items.

On the other hand, numerous materials are similar to the electrical bulk materials examined in this study. Plumbing, rebar, and sheetmetal materials are similar to the electrical activities on an industrial project because they all follow a structure's erection and do not regularly require prefabricated materials. In concept, these findings should be applicable to building construction and infrastructure projects. Although the sizes of buffers and planning levels may differ from an industrial project, the underlying notions remain the same.

Innovations

The following are innovations noted during the research that may be applied to the construction process.

- **Supply System Innovations** — Several organizations (including CII's Process Industry Practices) are investigating benefits of producing unique projects from standard components. Modular designs and design where suppliers have increasing responsibility for design and component integration are becoming more commonplace. Design collaboration between the engineer, supplier and constructor are becoming feasible. For example, an electrical supplier established, at their cost, a warehouse on the project site and guaranteed one-day delivery of standard electrical components. This is clearly a move to just-in-time material availability. On-site construction equipment rental suppliers offer guaranteed one day delivery and favorable rental terms in exchange for long term business.
- **Core Production System Innovations** — Some companies are increasing worker involvement and providing training to develop multi skilled personnel. Requirements for an experienced, involved work force is at odds with the current construction work force demographics. There appear to be opportunities to improve quality management. The construction industry norm is to discover and correct mistakes rather than to avoid mistakes in the first place. While levels of constructability and project production planning are normal today, there continues to be little input from construction workers. There appears to be increasing awareness of material management issues, but application of JIT and pull methods has not extended beyond delivery of simple materials. Minimal attention seems to be given to flow issues or concerns over process cycle time.
- **Customer Relations Innovations** — Several projects were being executed with alliance contracts established through long-term relationships between the owner and contractor.

This type of contracting arrangement provides fruitful territory for implementation of labor productivity enhancing methods because both parties directly share in the gain. Also, the project environment should be more stable and predictable where improvement efforts can be effectively controlled and measured.

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