

IDENTIFYING WASTE: APPLICATIONS OF CONSTRUCTION PROCESS ANALYSIS

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ABSTRACT

Implementation of lean production philosophy into the construction environment represents tremendous opportunity and challenge. One aspect challenging lean construction advocates is the systematic identification and quantification of waste, development of lean operations, and improvement verification.

Through case studies, this paper discusses the use of the Construction Process Analysis (CPA) technique as an appropriate tool for lean management in construction. Results indicate that for highly repetitive processes such as steel erection, CPA is effective at identifying and quantifying waste.

KEY WORDS

Lean construction, construction process analysis, structural steel construction process.

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INTRODUCTION

In the past two decades, the manufacturing industry has obtained great results in the area of productivity improvement, while the construction industry's productivity has remained stagnant. An important factor in this achievement has been the manufacturing industry's new production philosophy that has led to "Lean Production." This new production philosophy, developed by Japanese Industry, is currently being adopted in Europe and the United States. "Lean Production" provides a continuous improvement in the production process by eliminating various types of 'waste'.

Waste in construction and manufacturing includes delay times, quality costs, lack of safety, rework, unnecessary transportation trips, long distances, improper choice or management of methods or equipment and poor constructability (Alarcón 1993, Ishiwata 1997, Koskela 1992, Serpell 1995).

The potential impact of lean production philosophy on construction effectiveness is well-documented (Alarcón 1997, Koskela 1992). However, construction management often fails to identify or address waste in the construction process. One reason waste is not properly recognized is the absence of appropriate tools for measuring waste or value. Traditional process models in construction are not sufficient to distinguish between value adding and non-value adding activities. However, process analysis is a simple and effective tool that can be used to identify waste in processes. Process analysis focuses on elimination of the "Big 3" problems (waste, irrationality, and inconsistency). It investigates the overall flow of steps in a process and provides a method to improve the flow by making continuous improvements.

This paper discusses the implementation of process analysis as a modeling tool to identify and quantify waste in construction processes. Essentially, we attempt to answer the question, "*Can process analysis be used to identify and quantify waste in field construction operations?*" The Construction Process Analysis technique is illustrated through a case study example for steel erection processes.

CONSTRUCTION PROCESS ANALYSIS

Construction process analysis implements process charts and top-view flow diagrams common among process analysis techniques (Parker and Oglesby 1972, Ishiwata 1997). These charts and diagrams are based on standardized symbols under Japanese Industrial Standards JIS Z 8206. These symbols effectively describe the flow of processes and make it possible to quickly determine where the problem exists in the process. The symbols are divided into basic and supplementary symbols. The basic graphic consist of six symbols, including Operation, Transportation, Storage, Delay, Volume Inspection, and Quality Inspection, as shown in Table 1.

The process chart records each step of a construction operation. Additionally, the chart records flow within a unit, a section, a department, or between departments. Flow may include the sequential steps of a production operator, or it may include the sequential steps that the worker, part, or material goes through (Tanner 1985).

A flow diagram supplements the flow process chart. It is used to study each step by drawing a layout of the area in which a process flows. The layout will be understood more

easily by using the same symbols used on the worksheet. Figure 1 illustrates a plan view flow diagram that depicts the path, sequence and distances for the girder erection process.

Table 3 summarizes the consolidated girder erection field data.

Using the construction process chart worksheet and the plan view flow diagram, problems in the process are defined. Changing the sequence of steps, eliminating or adding steps, or changing the location of steps in the process are all possible methods for improving the process.

Table 1: Basic Graphic Symbols (JIS Z 8206)








| No. | Basic Step | Specific Step | Symbol | Meaning | Comment |
|-----|----------------|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | Operation | Operation |  | Alters the shape or other characteristics of a material, semi-finished product, or product | |
| 2 | Transportation | Transportation |   | Changes the location of a material, semi-finished product, or product | The transportation symbol is a circle measuring half the diameter of the circle used as the operation symbol. An arrow can be used in place of this small circle. The direction of the arrow does not imply the direction of transportation. |
| 3 | Retention | Storage |  | A scheduled accumulation of materials, parts, or products | |
| 4 | | Delay |  | An unscheduled accumulation of materials, parts, or products | |
| 5 | Inspection | Volume Inspection |  | Measurement of amounts of materials, parts, or products for comparison with the specified amounts to judge whether a discrepancy exists | |
| 6 | | Quality Inspection |  | Testing and visual inspection of materials, parts, or products for comparison with quality standards to judge whether defective (substandard) products are being produced. | |

Table 2: Flow Process Chart Example (Before improvement)

| Step | Title: Erection (3 Cranes) | | | Machine/ Tool | Distance (feet) | Crew Number | Crew Cost(\$/min) | Time (min) | Bare Cost(\$) | Date | |
|-----------------------------------------------------------|----------------------------|--------------|--------------------------|------------------|--------------------|----------------|----------------------|---------------|------------------|--------------------------|--------------------------|
| | Process Number | answer yh | Flow | | | | | | | Chart | Symbol |
| 1 Finding a member for erection | 1 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.15 | 0.81 | <input type="checkbox"/> | <input type="checkbox"/> |
| 2 Hook-on hoist and tagline | 2 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.48 | 2.60 | <input type="checkbox"/> | <input type="checkbox"/> |
| 3 Is there another member for lifting/maneuvering? | 3 | y | <input type="checkbox"/> | | | E-2 | 5.42 | 0.13 | 0.70 | <input type="checkbox"/> | <input type="checkbox"/> |
| 4 Is the number of members less than the limit of policy? | 4 | y | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> |
| 5 Lifting to hook another member | 5 | | <input type="checkbox"/> | Crane | 4.7 | E-2 | 5.42 | 0.38 | 2.06 | <input type="checkbox"/> | <input type="checkbox"/> |
| 6 Finding a member for erection | 1 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.22 | 1.19 | <input type="checkbox"/> | <input type="checkbox"/> |
| 7 Hook-on hoist and tagline | 2 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.22 | 1.19 | <input type="checkbox"/> | <input type="checkbox"/> |
| 8 Is there another member for lifting/maneuvering? | 3 | y | <input type="checkbox"/> | | | E-2 | 5.42 | 0.08 | 0.43 | <input type="checkbox"/> | <input type="checkbox"/> |
| 9 Is the number of members less than the limit of policy? | 4 | y | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> |
| 10 Lifting to hook another member | 5 | | <input type="checkbox"/> | Crane | 26 | E-2 | 5.42 | 0.95 | 5.15 | <input type="checkbox"/> | <input type="checkbox"/> |
| 11 Finding a member for erection | 1 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.15 | 0.81 | <input type="checkbox"/> | <input type="checkbox"/> |
| 12 Hook-on hoist and tagline | 2 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.23 | 1.25 | <input type="checkbox"/> | <input type="checkbox"/> |
| 13 Is there another member for lifting/maneuvering? | 3 | n | <input type="checkbox"/> | | | E-2 | 5.42 | 0.05 | 0.27 | <input type="checkbox"/> | <input type="checkbox"/> |
| 14 Lift/maneuver pieces | 6 | | <input type="checkbox"/> | Crane | 120 | E-2 | 5.42 | 2.95 | 15.99 | <input type="checkbox"/> | <input type="checkbox"/> |
| 15 Does member fit properly? | 7 | y | <input type="checkbox"/> | | | E-2 | 5.42 | 0.4 | 2.17 | <input type="checkbox"/> | <input type="checkbox"/> |
| 16 Connect by minimum requirements | 8 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 1.5 | 8.13 | <input type="checkbox"/> | <input type="checkbox"/> |
| 17 Unhook hoist | 9 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.33 | 1.79 | <input type="checkbox"/> | <input type="checkbox"/> |
| 18 Is there another member for connecting? | 10 | y | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> |
| 19 Lift member for another connecting | 11 | | <input type="checkbox"/> | Crane | 11 | E-2 | 5.42 | 1.75 | 9.49 | <input type="checkbox"/> | <input type="checkbox"/> |
| 20 Does member fit properly? | 7 | y | <input type="checkbox"/> | | | E-2 | 5.42 | 0.62 | 3.36 | <input type="checkbox"/> | <input type="checkbox"/> |
| 21 Connect by minimum requirements | 8 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 3.9 | 21.14 | <input type="checkbox"/> | <input type="checkbox"/> |
| 22 Unhook hoist | 9 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 1.92 | 10.41 | <input type="checkbox"/> | <input type="checkbox"/> |
| 23 Is there another member for connecting? | 10 | y | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> |
| 24 Lift member for another connecting | 11 | | <input type="checkbox"/> | Crane | 30 | E-2 | 5.42 | 1.55 | 8.40 | <input type="checkbox"/> | <input type="checkbox"/> |
| 25 Does member fit properly? | 7 | y | <input type="checkbox"/> | | | E-2 | 5.42 | 0.52 | 2.82 | <input type="checkbox"/> | <input type="checkbox"/> |
| 26 Connect by minimum requirements | 8 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 1.87 | 10.14 | <input type="checkbox"/> | <input type="checkbox"/> |
| 27 Unhook hoist | 9 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 2.98 | 16.15 | <input type="checkbox"/> | <input type="checkbox"/> |
| 28 | | | | | | | | | | | |
| 29 | | | | | | | | | | | |
| Total | | | 27 steps | | 191.7 | | | 23.33 | 126.46 | 9times | 13times |
| Notes | | | | | | | | | | 13.43min | 2.32min |
| | | | | | | | | | | Group: | By: |

Value added
 Non-value added but necessary
 Non-value added and unnecessary

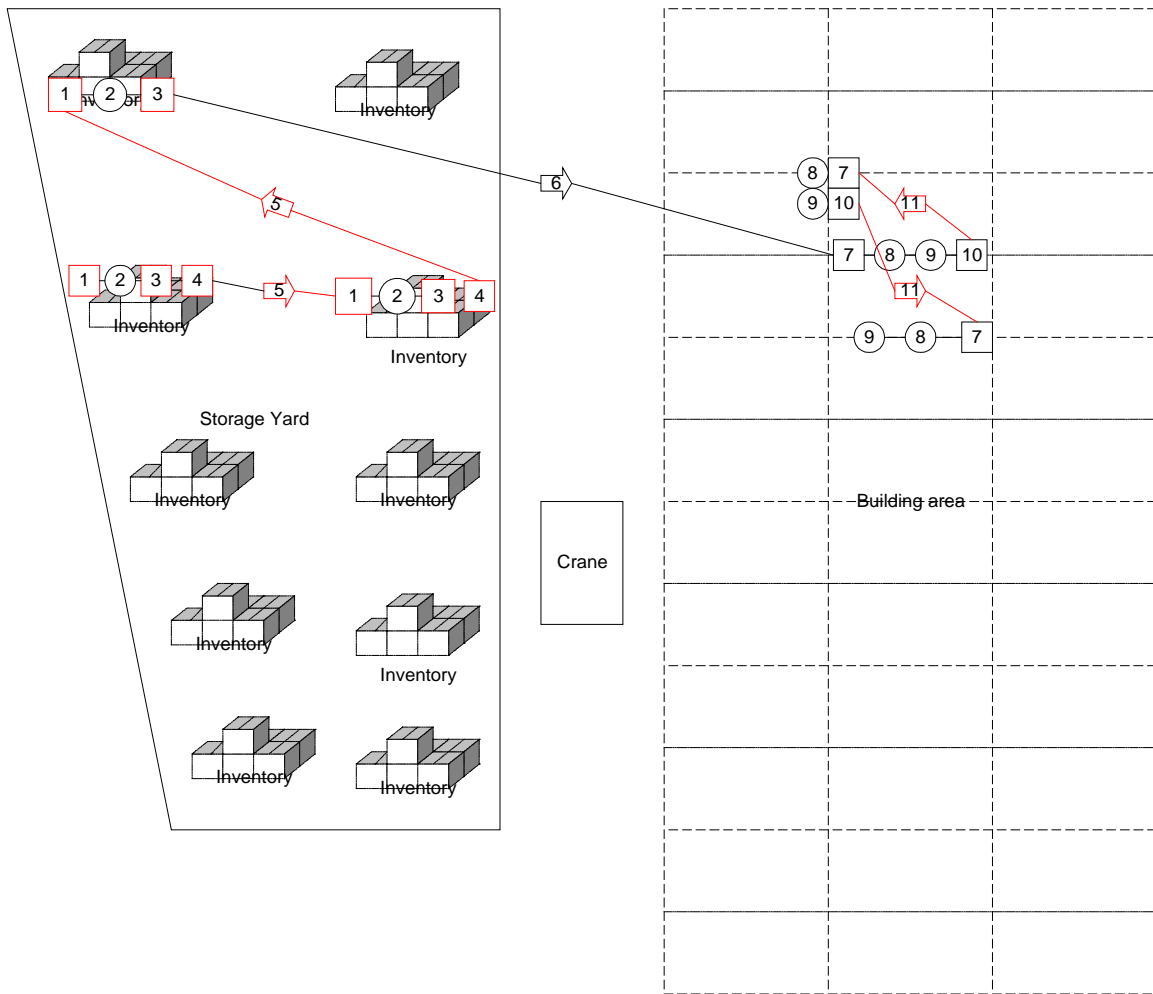


Figure 1: Example of Plan View Flow Diagram (Before Improvement)

Table 3: Data Chart (Before Improvement)

| Step | No. of Steps | Time (min) | Costs (\$) | Distance (feet) |
|-----------------|--------------|------------|------------|-----------------|
| Operation | 9 | 13.43 | 72.79 | 0 |
| Vol. Inspection | 13 | 2.32 | 12.57 | 0 |
| Transportation | 5 | 7.58 | 41.08 | 191.7 |
| Total | 27 | 23.33 | 126.45 | 191.7 |

For example, as shown in Figure 1, the steps for finding and hooking the girders flow from one inventory to another because of the random delivery of steel members. The fabricator sent the steel members to the site according to their own fabrication sequence rather than the site construction schedule. Compare this flow diagram to that shown in Figure 2 wherein the steel members required for erecting bay 5 were set and blocked at the same location. As a result, unnecessary ground activities associated with finding the correct members are reduced. Likewise, rationalizing the sequence of connecting each girder reduces unnecessary movement of materials or workers on the structure itself. If the steps of connecting each

girder can flow as shown in Figure 2, transportation distances and unnecessary movement of workers can be reduced significantly. Table 7 illustrates the process activity work sheet for the improved process.

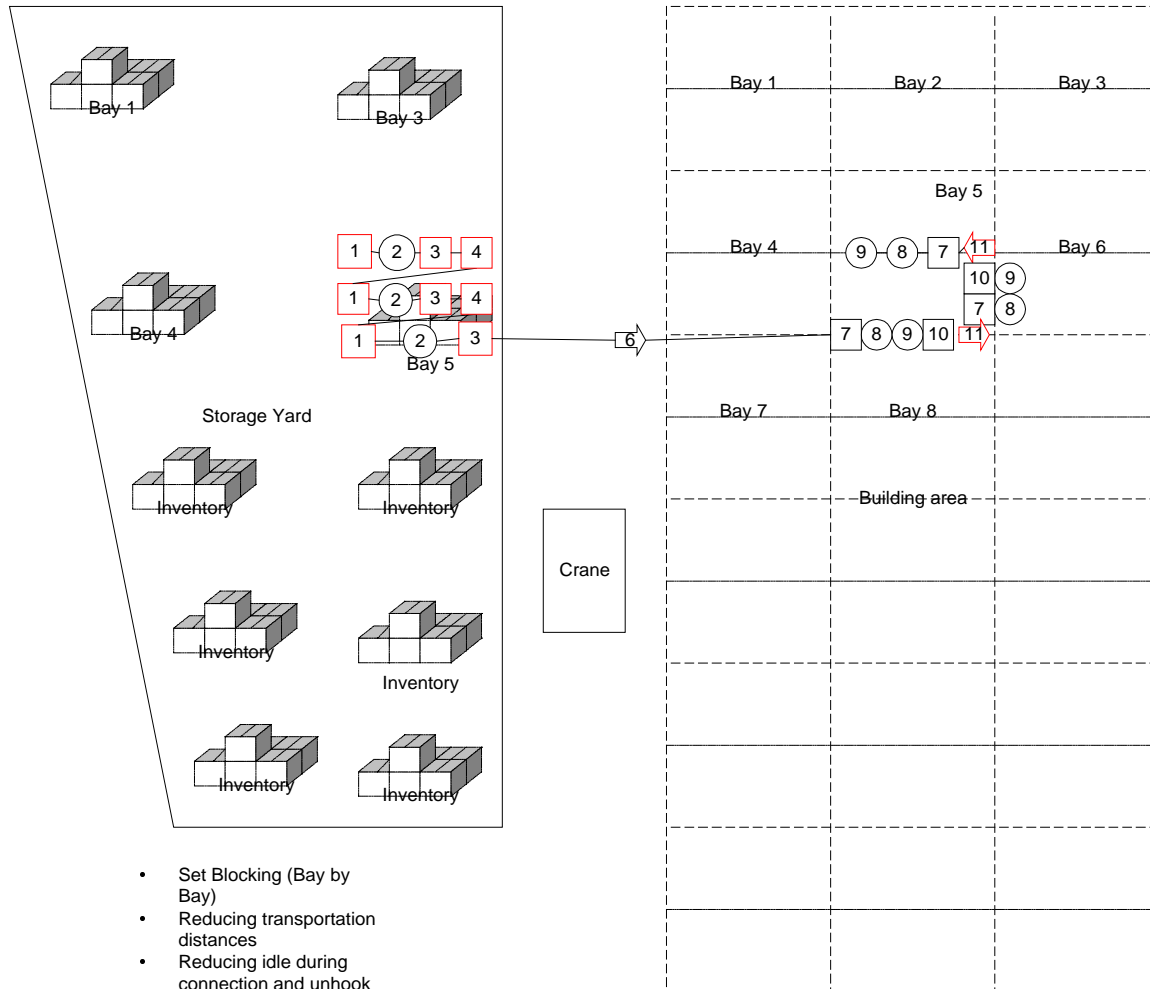


Figure 2: Plan View (After Improvement)

Tables 4 and 5 illustrate the results of the analysis for the process of erecting three girders before and after improvement. It is important to note that all operation steps shown are represented as value-added activities because they were directly related to production. However, each operation may involve waste such as worker's idle time, unnecessary movement or rework. Thus, one important finding is that CPA analysis conducted at this level of detail cannot locate wastes that are embedded in individual operations. However, CPA analysis is quite capable of delineating differences between processes in terms of the number of process steps and the proportion of value adding and non-value adding steps.

Table 4: Process Analysis (Before Improvement)

| Chart | | Value added | | | | Non-value added but Necessary | | | | Non-value added and Unnecessary | | | |
|--------|--------|-------------|------------|-----------|--------------|-------------------------------|------------|-----------|--------------|---------------------------------|------------|-----------|--------------|
| Symbol | Number | Number | Time (min) | Cost (\$) | Dist. (feet) | Number | Time (min) | Cost (\$) | Dist. (feet) | Number | Time (min) | Cost (\$) | Dist. (feet) |
| ○ | 9 | 9 | 13.43 | 72.79 | 0.00 | 0 | 0 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0.00 |
| □ | 13 | 0 | 0 | 0.00 | 0.00 | 6 | 2.06 | 11.17 | 0.00 | 7 | 0.26 | 1.41 | 0.00 |
| ⇨ | 5 | 0 | 0 | 0.00 | 0.00 | 1 | 2.95 | 15.99 | 120.00 | 4 | 4.63 | 25.09 | 71.70 |
| Total | 27 | 9 | 13.43 | 72.79 | 0.00 | 7 | 5.01 | 27.15 | 120.00 | 11 | 4.89 | 26.50 | 71.70 |

Table 5: Process Analysis (After Improvement)

| Chart | | Value added | | | | Non-value added but Necessary | | | | Non-value added and Unnecessary | | | |
|--------|--------|-------------|------------|-----------|--------------|-------------------------------|------------|-----------|--------------|---------------------------------|------------|-----------|--------------|
| Symbol | Number | Number | Time (min) | Cost (\$) | Dist. (feet) | Number | Time (min) | Cost (\$) | Dist. (feet) | Number | Time (min) | Cost (\$) | Dist. (feet) |
| ○ | 9 | 9 | 8.33 | 45.15 | 0.00 | 0 | 0 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0.00 |
| □ | 13 | 0 | 0 | 0.00 | 0.00 | 6 | 1.54 | 8.35 | 0.00 | 7 | 0 | 0.00 | 0.00 |
| ⇨ | 3 | 0 | 0 | 0.00 | 0.00 | 3 | 4.40 | 23.85 | 128.00 | 0 | 0 | 0.00 | 0.00 |
| Total | 25 | 9 | 8.33 | 45.15 | 0 | 9.00 | 5.94 | 32.19 | 128 | 7.00 | 0 | 0.00 | 0 |

Table 6 quantifies the effects of the improvement plan in terms of the number of steps, time (min), cost (\$), and distance (feet). In this simple example, the number of steps for erecting the girders was reduced from 27 to 25; time was reduced from 23.33 min. to 14.27 min.; cost was reduced from \$126.45 to \$77.34; distance was reduced from 191.7 feet to 128 feet.

Table 6: Comparison of Original Process with Improved Process

| Step | No. of Steps | | | Time (min) | | | Cost (\$) | | | Distance (feet) | | |
|-----------------|--------------|-------------|--------|-------------|-------------|--------|-------------|-------------|--------|-----------------|-------|--------|
| | Before | After | Effect | Before | After | Effect | Before | After | Effect | Before | After | Effect |
| | Improvement | Improvement | | Improvement | Improvement | | Improvement | Improvement | | Improvement | | |
| Operation | 9 | 9 | 0 | 13.43 | 8.33 | 5.1 | 72.79 | 45.15 | 27.64 | 0 | 0 | 0 |
| Vol. Inspection | 13 | 13 | 0 | 2.32 | 1.54 | 0.78 | 12.57 | 8.35 | 4.23 | 0 | 0 | 0 |
| Transportation | 5 | 3 | 2 | 7.58 | 4.4 | 3.18 | 41.08 | 23.85 | 17.24 | 191.7 | 128 | 63.7 |
| Total | 27 | 25 | 2 | 23.33 | 14.27 | 9.06 | 126.45 | 77.34 | 49.11 | 191.7 | 128 | 63.7 |

Additionally, CPA may also be useful to compare a project with the similar processes of other projects. For example, the work processes of two additional case studies investigated in this research differ significantly. Case Studies 2 and 3 were a hospital and university building respectively. CPA provides an objective comparison of the two processes as shown in Figure 3. Note that the university building steel erection process contained much greater non-value adding, unnecessary activities. This comparison provides valuable information for allocating and optimizing lean production resources.

CONCLUSION

This paper illustrates the value of using the construction process analysis technique for identifying and quantifying waste in construction operations. The use of the CPA method on three projects reveals both benefits and problems. As a communication tool, CPA can be presented graphically in a way that easily shows the progress of a given process. Problems

Table 7: Flow Process Chart Example (After improvement)

| Title: Erection (3 Gired's) | | | | | | | | | | | Date | |
|-----------------------------------------------------------|-------------------|------------|-------------------------------------|---------------|-----------------|-------------|--------------------|------------|----------------|-------------------------------------|-------------------------------------|--|
| Step | Process Number | answer y/n | Flow | Machined Tool | Distance (feet) | Crew Number | Crew Cost (\$/min) | Time (min) | Bare Cost (\$) | Chart | Syrrbol | |
| 1 Finding a member for erection | 1 | | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> | |
| 2 Hook-on hoist and tagline | 2 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.48 | 2.60 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 3 Is there another member for lifting/maneuvering? | 3 | y | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> | |
| 4 Is the number of members less than the limit of policy? | 4 | y | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> | |
| 5 Finding a member for erection | 1 | | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> | |
| 6 Hook-on hoist and tagline | 2 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.22 | 1.19 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 7 Is there another member for lifting/maneuvering? | 3 | y | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> | |
| 8 Is the number of members less than the limit of policy? | 4 | y | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> | |
| 9 Finding a member for erection | 1 | | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> | |
| 10 Hook-on hoist and tagline | 2 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.23 | 1.25 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 11 Is there another member for lifting/maneuvering? | 3 | n | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> | |
| 12 Lift/maneuver pieces | 6 | | <input checked="" type="checkbox"/> | Crane | 120 | E-2 | 5.42 | 2.95 | 15.99 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 13 Does member fit properly? | 7 | y | <input type="checkbox"/> | | | E-2 | 5.42 | 0.4 | 2.17 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 14 Connect by minimum requirements | 8 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 1.5 | 8.13 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 15 Unhook hoist | 9 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.33 | 1.79 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 16 Is there another member for connecting? | 10 | y | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> | |
| 17 Lift member for another connecting | 11 | | <input checked="" type="checkbox"/> | Crane | 4 | E-2 | 5.42 | 0.75 | 4.07 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 18 Does member fit properly? | 7 | y | <input type="checkbox"/> | | | E-2 | 5.42 | 0.62 | 3.36 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 19 Connect by minimum requirements | 8 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 1.7 | 9.21 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 20 Unhook hoist | 9 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 1.2 | 6.50 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 21 Is there another member for connecting? | 10 | y | <input type="checkbox"/> | | | E-2 | 5.42 | | 0.00 | <input type="checkbox"/> | <input type="checkbox"/> | |
| 22 Lift member for another connecting | 11 | | <input checked="" type="checkbox"/> | Crane | 4 | E-2 | 5.42 | 0.7 | 3.79 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 23 Does member fit properly? | 7 | y | <input type="checkbox"/> | | | E-2 | 5.42 | 0.52 | 2.82 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 24 Connect by minimum requirements | 8 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 1.87 | 10.14 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 25 Unhook hoist | 9 | | <input type="checkbox"/> | Crane | | E-2 | 5.42 | 0.8 | 4.34 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | |
| 26 | | | | | | | | | | | | |
| 27 | | | | | | | | | | | | |
| 28 | | | | | | | | | | | | |
| 29 | | | | | | | | | | | | |
| Total | | | 25 steps | | 128 | | | 14.27 | 77.34 | 9times | 13times | |
| Notes | After Improvement | | | | | | | | | | | |
| | | | | | | | | | | 8.33min | 4.4min | |
| | | | | | | | | | | Group: By: | | |

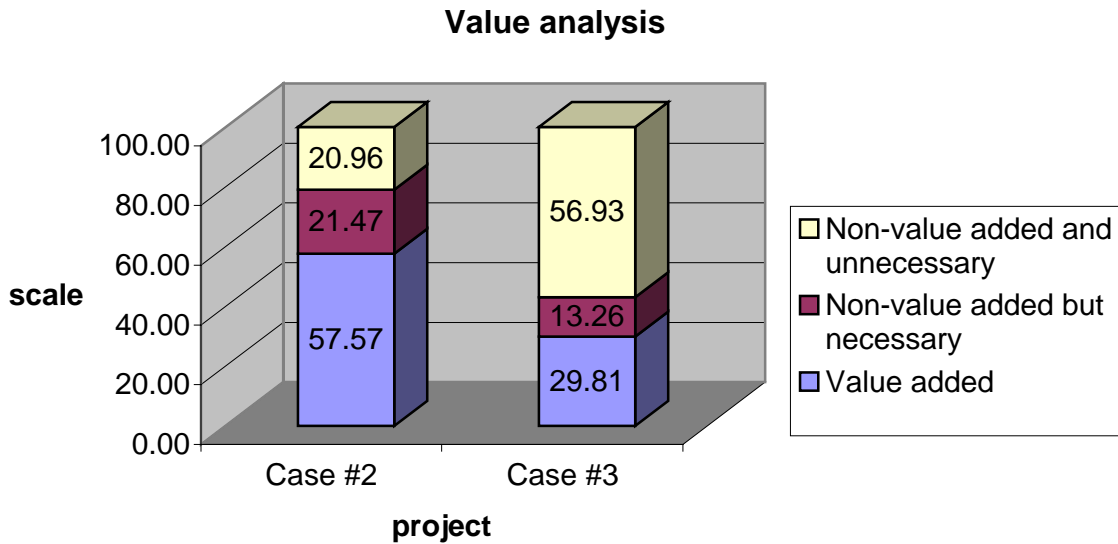


Figure 3: Comparison of the Erection Processes

that exist in the process can be easily identified. All data can be gathered through simple observation of the process. The data that are measured and recorded on the worksheet can be organized for developing an improvement plan. CPA can be completed in a relatively short amount of time. Of course, the time required will vary, depending on the characteristics of the work task to be analyzed. CPA can be used at any time, with no special preparation or tools required. The improvement plan can be made in a short time and implemented right away. As mentioned above, it took approximately 5 hours to analyze one process of the case studies, from measuring all necessary information to making an improvement plan. Additionally, CPA is a very simple method. Personnel from all levels of an organization can understand CPA and use it easily. A particular advantage is that workers on site can easily participate in analyzing their processes.

Another benefit of CPA analysis is the inter-project comparisons it permits when the analysis is performed on multiple projects. Such inter-project analyses provide process goals and standards that simple unit cost analyses are incapable of providing. Some may contend that benefits of CPA analyses describe in these case studies would not have been as dramatic if the jobsites had been well organized and efficiently operated. Yet, large, reputable structural steel erectors in the Denver region ran all three of the projects included in this research. In this light, perhaps the largest benefit of CPA analysis is to make visible poor sequence and waste that is prevalent on construction jobsites.

However, the CPA method is not a complete tool for identifying waste in construction processes. One common description of "waste" categories is:

1. Defects
2. Over-production
3. Unnecessary Processing

4. Unnecessary People Moves
5. Unnecessary Movement of Material
6. Waiting
7. Inventories
8. Designing Something that Does Not Meet the Client's Needs

According to these categories, CPA is not particularly helpful for identifying or quantifying wastes due to defects, over-production, or designing something insufficient for a client's needs. CPA is helpful in identifying waste associated with unnecessary processing, people moves, material moves and waiting time. The CPA flow diagram may indicate unnecessarily large material inventories. The CPA method uses seven standard symbols that are insufficient for measuring idle or waiting times that occur within an individual work process. To accurately quantify ineffective activity or waiting within individual processes, data collection would need to be conducted at a very fine level of detail. Based on our case studies, we are not certain that the benefits of a detailed CPA analysis would outweigh its costs.

In addition, it is unclear whether the cost, time, and distance data used in these studies are sufficient metrics by which to characterize a process. CPA analysis quantifies these various metrics using an average value that is derived from several instances of each work activity. There is no explicit measurement of uncertainty in individual activity times. Neither is there is an overt measure of "flow" in a CPA analysis, rather one must imply flow (or its absence) by evaluating waiting times.

The examples used in this work focused on individual major steel member erection processes. An improvement plan for the overall project or even an overall steel construction process evaluation was not attempted. This allows the possibility of sub-optimization. Finally, our examples incorporated highly repetitive processes. The anticipated benefits for less repetitive or less structured work will likely be smaller. We anticipate conducting additional CPA analyses on other less structure construction processes such as concrete placement and formwork erection.

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