Applications of Product Process Analysis For Improving the Construction Process of Structural Steel

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요 약

A construction process consists of value adding activities and non-value adding activities, necessary or unnecessary. If construction personnel can eliminate inefficient and/or unnecessary activities within the process, they may have a great opportunity to improve their construction process.

The Product Process Analysis (PPA) technique, which was developed in the manufacturing industry, can be applied for identifying wastes in the construction process and ultimately improving the process itself. It provides useful tools, such as a process chart worksheet and flow diagram, for mapping the flow of construction activities with predetermined standardized symbols. These tools make people understand the flow of activities more easily, identify value adding/non-value adding activities within the process, and areas where the process can be improved.

The example applications of PPA are demonstrated in the paper through the case studies implemented on the construction process of structural steel. The results of case studies indicate that PPA technique was effective at identifying and removing wastes in the steel construction process. It is also found that PPA technique is more effective for improving highly repetitive construction processes.

키워드 : Construction Process, Waste, Value, Product Process Analysis, Process Chart Worksheet, Process Flow Diagram, Structural Steel

1. Introduction

1.1 Research Background and Objectives

Significant 'waste' exists in the construction industry. Womack and Jones (1996) defined waste, in a broader concept, as any human activity which absorbs resources but create no 'value'. Waste in construction includes re-work, unnecessary transportation trips, delay times, stoppages, work not done, extra supervision, improper choice or management of methods, etc. (Alarcôn 1997, Serpell, 1997). While not all of non-value adding activities are wastes, any non-value adding activities that are wastes should be eliminated to improve the quality of construction processes. In the lean approach, Ballard at el. (2001) suggests that designing production systems to maximize value and minimize waste is always right thing to do. They argue that maximizing value and minimizing waste generates the greatest profit, the difference between price and cost.

However, in general, construction personnel fail to notice that the construction are carried out with a great number of wastes and/or non-value adding activities. One of the reasons is that there is not an efficient and simple method for distinguishing between value adding and non-value adding activities.

Therefore, the primary objective of the research is to develop an efficient tool for identifying non-value adding activities through the analysis of construction productive processes. Eliminating waste, specifically unnecessary non-value adding activities, will lead to the improvement of those construction processes. The effect of improvement will be more significant for highly repetitive processes.

1.2 Research Methodology and Scope

In the research, Product Process Analysis (PPA) will be applied to identify non-value adding activities in the construction processes. In the manufacturing industry, it is used as a technique for studying the flow of processes in the purpose of redesigning or improving the sequence of processing activities.

However, the original product process analysis method and its useful tools are not sufficient to achieve the research objective because it does not differentiate between the value and non-value adding activities. Thus, the format of the tools and the terms for symbols as they are applied to construction processes were somewhat modified, and the functions of implementing the analysis

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were also modified. For example, the modified PPA method identifies and classifies the characteristics of activities within a construction process. It facilitates the value stream analysis for the flow of the process as an additional function.

In order to show an application of PPA, the research implemented couple of case studies by focusing on a specific construction process. For the trial applications of PPA to a construction process, a simple and repetitive process, such as the steel construction process, was chosen. Unlike manufacturing, construction processes are not usually repetitive and may vary according to the change of site conditions. Thus, the process of steel construction, which has many cyclic activities, has been selected for the first trial of PPA. The results of case studies will be summarized in the paper.

2. Product Process Analysis (PPA)

2.1 Product Process Analysis (PPA) Defined

Product process analysis is a technique for analyzing the flow of operations in a process by representing the processes with standardized symbols in terms of the flow of materials, parts, and/or products. It is used for finding a way to make a product more easily, cost effectively, and quickly. Efforts should be focused where the returns will be the greatest. For example, processes that require excessive amounts of time or involve unnecessary movement or rework should be improved first. Ishiwata identified the following as potential areas for improvement (1997):

1) Unnecessary delay points along the line
2) Unnecessary transportation trips
3) Unnecessary long transportation distances
4) Problems posed by the choice of transportation methods
5) Opportunities combine operations and inspection

After checking these points, processes can be improved by changing the sequence of work and the equipment layout or by redesigning the operating processes. To change the sequence of processes or redesign them for the purpose of improvement, some tools, such as process charts and top-view flow diagrams using standardized symbols, will be very useful.

However, the product process analysis technique and its useful tools are not precise in analyzing construction processes because they originate from the manufacturing industry. Thus, the format, terms, and some functions of the tools as they are applied to construction processes were somewhat modified. Specifically, the modified tools provide an easier way to identify and eliminate unnecessary activities in a construction process by dividing all activities into three categories and make the flow of process more simple and efficient.

2.2 Standardized Symbols

Standardized symbols effectively describe the flow of activities within processes for the purpose of analysis. Using these symbols makes it easier for everyone involved in a process to understand its flow. It also makes it possible to quickly determine where the problem exists in the process and to provide effective solutions. The basic graphic symbols are usually used to represent the basic activities in a process. They consist of six symbols, including conversion, transportation, storage, waiting, volume inspection, and quality inspection as shown in Table1. The name of some symbols for process chart, which are originated from JIS Z 8206, was modified according to the characteristics of construction processes.

These symbols are useful in making process chart worksheets and process flow diagrams common among PPA techniques (Parker 1972, Ishiwata 1997). They make it easier to understand and analyze the flow of activities within the process because the flow of activities can be described visually.

Table 1. Basic Standardized Symbols
(Source from Japanese Industrial Standards, JIS Z 8206)

No.	Symbol	Name	Meaning
1	○	Conversion	An entity[1] is intentionally changed in any of its physical or chemical characteristics.
2	⇨	Transport-ation	A person moves from one workplace to another or an entity is transferred.
3	▽	Storage	An entity is accumulated according to the schedule.
4	D	Waiting	An entity is waiting for the next performance since it is not required immediately.
5	□	Volume Inspection	The amount or the size of an entity is examined, or the inventory of materials is identified.
6	◇	Quality Inspection	An entity is tested and visually inspected for verifying the discrepancy between the quality of the entity and the quality standards.

1) An entity is either a material or a unit of information.

2.3 Process Chart Worksheet

A process chart worksheet is established to describe a specific construction process that has been targeted for improvement. The items involved in the worksheet may be different, depending on the objective of the people who use it. However, the basic content of the items is similar to that of general PPA method. The worksheet that was used to analyze a steel construction process in the research included the following basic items: the title of the construction process, the description of each activity within the process by sequence, the symbols for representing each activity, the distance of any transportation, the time spent to complete each activity. In addition to these basic items, the worksheet added some items to describe and analyze the steel construction process more efficiently as follows: the process number assigned to each activity, the answer about the question for requiring a judgement or decision, the crew assigned to finish each activity, the estimated cost to finish each activity, and the flow of activities with symbols.

The flow of construction activities described on the right side of the work sheet divides all activities into three categories: value added, non-value added but necessary, and non-value added and unnecessary activities. The scope of each category is described in Table 2.

Table 2. The Scope of Three Categorized Activities

Categories of Activities	Scope of Each Category
Value added	Those activities which are directly related to the production of the product.
Non-value added but necessary	Those activities which are not directly related to the production of the product, but required to make the process flow[2].
Non-value added and unnecessary	Those activities which are neither directly related to the production of the product nor required in the process.

2.4 Process Flow Diagram

A process flow diagram is drawn up with the standardized symbols and the process numbers that are represented in the process chart worksheet. Using the process flow diagram with the process chart worksheet makes it easier and faster to understand the flow of the steps. The flow diagram is particularly useful in identifying the activity that are unnecessary or inefficient because it illustrates the flow of activities in the process visually. For instance, the diagram reveals where the unnecessary movements were made, where the rework or unnecessary work was done, where the extra supervision was implemented, or how congestive flow of the process was practiced.

2) For example, although the activitiess such as necessary movements or critical inspections do not make any production, but they may be necessary to continue the production process.

3. Typical Construction Process of Structural Steel

The research has focused on the applications of product process analysis on the construction processes. The process of steel construction has been selected for the first trial of PPA. The results of case studies indicate that the PPA technique is effective for improving highly repetitive construction processes such as steel erection.

Therefore, understanding the typical construction process of structural steel will be useful in understanding the case studies applying the PPA technique. The steel construction process that is represented in the research has been developed based on the ATLSS[3] Report given by Mario Eraso and E. Sarah Slaughter (1994) as illustrated in Figure 1. It has identified six main stages: unloading, shake-out, erecting, plumbing, permanently connecting, and decking.

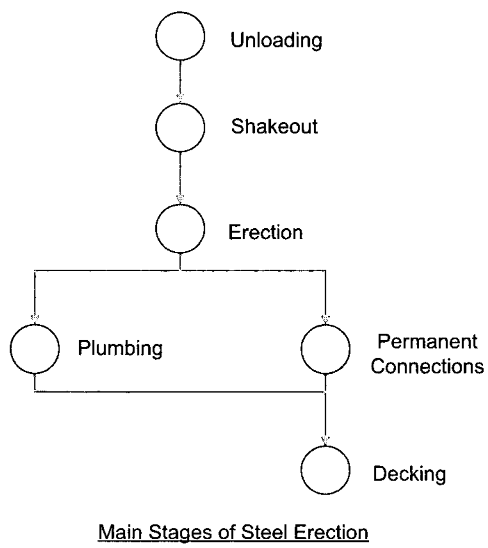

Figure 1. Typical Construction Process of Structural Steel

Among them, the unloading process starts when steel members arrive on site. The members that are unloaded are usually kept on site before the shake-out or erection starts. The shake-out process is a preliminary process that is necessary for erecting steel members. In this stage, each steel member is inspected whether or not it is

3) Advanced Technology for Large Structural Systems.

prepared for the erection. Then, members that must be erected are shaken-out. The erection process is the most important part of the steel construction process. It usually takes more time and is more costly rather than the other processes. Thus, it is natural to focus on erection to improve the steel construction process. Because the steel construction process consist of a greater number of repetitive tasks, even small changes in the process will result in some degree of improvement.

4. Applications of PPA

This section demonstrates an example of a PPA application on the structural steel construction process of the Humanities Building (Case Study 1)[4]. The researcher visited the job site and observed construction processes to be analyzed. Inefficient and/or unnecessary activities were identified and eliminated within the process by using the PPA techniques.

For example, the erection process for installing three beams was analyzed and improved according to the following procedures.

4.1 Drawing up a process chart worksheet and a flow diagram

All necessary information for erecting the steel members was measured and recorded on the process chart worksheet, as illustrated in Appendix I. In this process, there were a total of 41 activities, ranging from 'finding a member for erection' to 'unhook hoist.' These activities were videotaped, and the elapsed times for each activity were recorded. The distances for transportation activities were also measured. Each activity was classified into one of the three categories as defined in Table 2. The top view flow diagram of the process is illustrated in Figure 2. The diagram is useful in understanding the flow of the process because it describes the erection situation graphically. It facilitated the classification of activities with the process chart worksheet.

4.2 Organizing the analysis results

Table 3 provides an organized data chart of the erection process. It shows the result of the value stream analysis measured on the right side of the worksheet. This result indicates that two operation, sixteen volume inspection, and six transportation activities were regarded as non-value added and unnecessary activities. It also shows that 10 operations were value added activities. However, if the analysis for these operations entered into more details, more unnecessary sub-activities, such as worker's idle time or unnecessary movement, could be separated from these operations. Thus, it is important to note that PPA analysis conducted at this level of detail cannot locate those unnecessary sub-activities that are embedded in individual operations. However, the PPA technique is quite capable of delineating the flow of classified activities reasonably within processes and the proportion of value adding and non-value adding activities.

4.3 Developing an improvement plan

As illustrated in Figure 2, the workers on the project installed only one beam at a time. This causes unnecessary movement of the crane because it can lift up to five beams simultaneously (according to OSHA regulation). If the crane lifts three beams simultaneously as illustrated in Figure 3, the time, cost, and distance to complete the process will be simply reduced. Moreover the effect of only the removal of unnecessary movement will be significant if the removal is applied to all repetitive erection cycles.

Another problem according in this process resulted from worker error. Since the worker who worked on the storage yard did not hook the right steel member, that steel had to exhaust one cyclic activities wastefully. The steel worker's attention and responsibility to check the steel members is an important one. To prevent the worker's confusion, the steel members may be set-blocked bay by bay. Another problem occurred because a steel member did not fit properly onto other steel members installed, resulting in the stoppage of work and time wasted. The precise fabrication of steel members is, therefore, a very important factor as well in improving the erection process. Appendix II shows the example of the process chart worksheet developed considering these improvement points.

4.4 Evaluating the improved plan

Table 4 illustrates the result of value stream analysis for the process of erecting three beams after improvement. It is important to note that the number of activities regarded as non-value added activities could be reduced from thirty one to nineteen through the improved plan. Even the number of value added activities was reduced from ten to nine because the activity for aligning holes to fit a steel member could be removed.

4) It was built on the campus of the University of Colorado at Boulder in 1998. This project had many constraints, such as very narrow storage yards or tree/existing facilities protection.

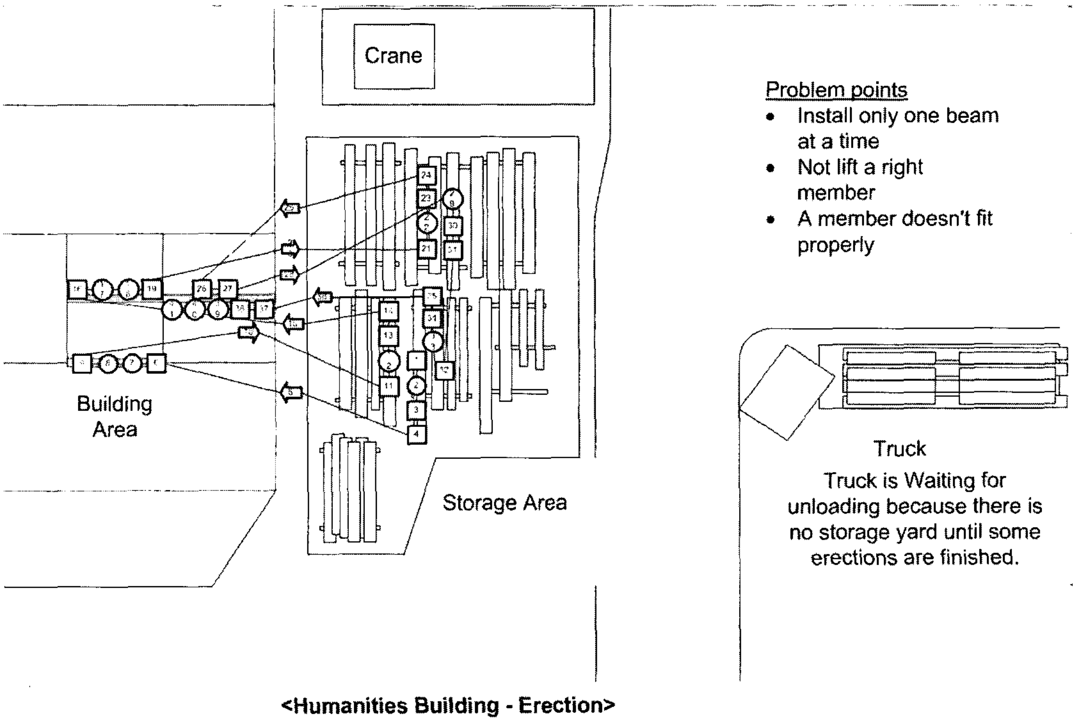

Figure 2. Example of Plan View Flow Diagram (Before Improvement)

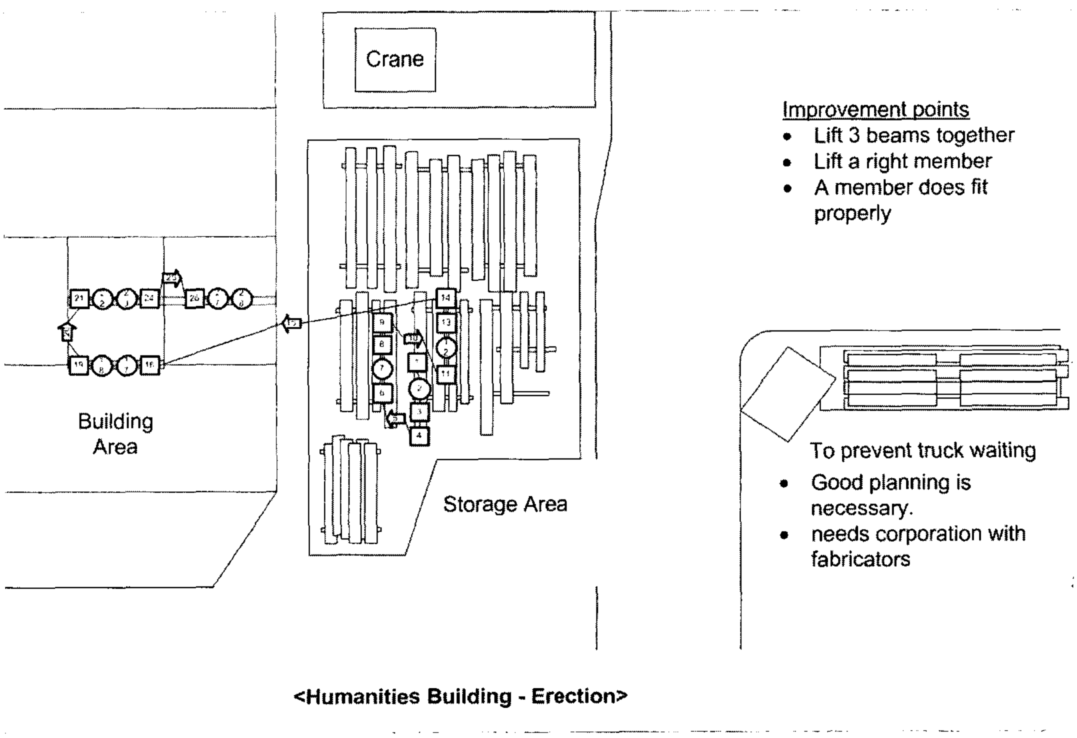

Figure 3. Example of Plan View Flow Diagram (After Improvement)

The effects of the improvement plan are quantified in terms of the number of activities, time (min), cost ($), and distance (feet) and summarized as shown in Table 5. The number of activities for erecting 3 beams was decreased from 41 to 28; time was reduced from 20.36 min. to 8.85 min.; cost was reduced from $110.35 to $47.97; distance was decreased from 499 feet to 110 feet.

4.5 Comparing the construction processes through the value analysis

PPA may also be useful to compare a project with the similar processes of other projects. In fact, it is observed that the flows of activities from two additional case studies investigated in the research differ significantly. These case studies were the J. D. Edwards office (Case Study 2) and the Longmont United hospital building (Case Study 3) respectively.

For example, the erection process in the Case Study 2 was to install three girders, while the same process in Case Study 1 was to erect three beams. Even though the productions of these two processes were not identical, the steps of implementing those processes were basically the same, and thus, can be compared. The erection process of Case Study 2 seemed to be more efficient than in Case Study 1 because the Humanities Building project had many site constraints. However, rather than comparing these two processes so subjectively, some criteria can be developed for a more objective comparison. The value stream analysis through the PPA technique can serve as a criterion for objectively comparing processes that have similar work activities. Table 6 shows the data chart that is organized through the value stream analysis.

Table 6. Data Chart of Value Analysis for Erection Processes

Case	Time (min)	Value Analysis	Time (min)	Rate	Score
1	20.36	Value-added	6.07	6.96[5]	29.81
		Non-value added, necessary	2.70	3.09	13.26
		Non-value added, unnecessary	11.59	13.28	56.93
2	23.33	Value added	13.43	13.43	57.57
		Non-value added, necessary	5.01	5.01	21.47
		Non-value added, unnecessary	4.89	4.89	20.96

Since these two processes did not include exactly the same work, the scores for value analysis were made to give the time scale (23.33 min. = 100%). They are the percentages of each rate that is necessary to compare the processes by using the value stream analysis. Figure 4 simply shows the bar chart of these scores. It indicates that the

5) Ex. (6.07 × 23.33)/20.36 = 6.96

Table 3. The Result of Value Stream Analysis (Before Improvement)

Chart		Value added				Non-value added but Necessary				Non-value added and Unnecessary			
Symbol	Number	Number	Time (min)	Cost ($)	Distance (feet)	Number	Time (min)	Cost ($)	Distance (feet)	Number	Time (min)	Cost ($)	Distance (feet)
○	12	10	6.07	32.90	0.00	0	0.00	0.00	0.00	2	4.72	25.58	0.00
□	22	0	0.00	0.00	0.00	6	1.58	8.56	0.00	16	1.92	10.41	0.00
⇨	7	0	0.00	0.00	0.00	1	1.12	6.07	76.00	6	4.95	26.83	423.00
Total	41	10	6.07	32.90	0.00	7	2.70	14.63	76.00	24	11.59	62.82	423.00

Table 4. The Result of Value Stream Analysis (After Improvement)

Chart		Value added				Non-value added but Necessary				Non-value added and Unnecessary			
Symbol	Number	Number	Time (min)	Cost ($)	Distance (feet)	Number	Time (min)	Cost ($)	Distance (feet)	Number	Time (min)	Cost ($)	Distance (feet)
○	9	9	5.65	30.62	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
□	14	0	0.00	0.00	0.00	6	0.87	4.72	0.00	8	0.00	0.00	0.00
⇨	5	0	0.00	0.00	0.00	5	2.33	12.63	110.00	0	0.00	0.00	0.00
Total	28	9	5.65	30.62	0.00	11	3.20	17.34	110.00	8	0.00	0.00	0.00

Table 5. Comparison of Original Process with Improved Process

Activities	Number of Activities			Time (min)			Cost ($)			Distance (feet)		
	Original	Improved	Effect	Original	Improved	Effect	Original	Improved	Effect	Original	Improved	Effect
Operation	12	9	3	10.79	5.65	5.14	58.48	30.62	27.86	0	0	0
Volume Inspection	22	14	8	3.5	0.87	2.63	18.97	4.72	14.25	0	0	0
Transportation	7	5	2	6.07	2.33	3.74	32.90	12.63	20.27	499	110	389
Total	41	28	13	20.36	8.85	11.51	110.35	47.97	62.38	499	110	389

Humanities Building steel erection process contained much greater non-value adding, unnecessary activities.

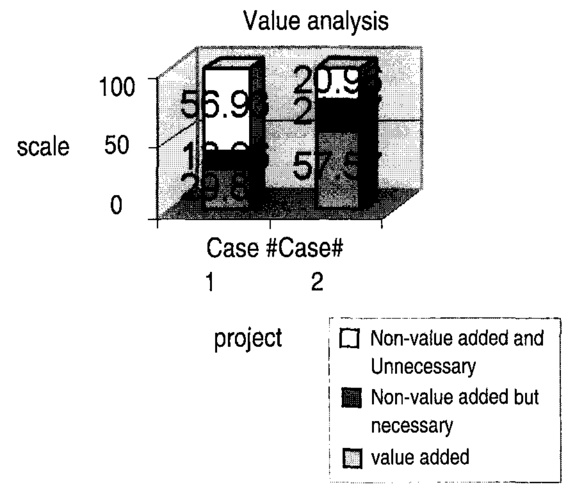

Figure 4. Comparison of the Erection Processes

6. Conclusion

To identify non-value adding activities in construction processes, an efficient tool or method for analyzing those processes is necessary. The research has used the 'Product Process Analysis (PPA)' technique that was developed in the manufacturing industry for the purpose of eliminating or reducing non-value adding activities and improving a construction process. The tools for using the PPA technique include a process chart worksheet and a top view flow diagram drawn up with the standardized symbols. They are applied specifically to analyze the flow of construction activities through value stream analysis. Each activity in the process is identified as value adding, non-value adding but necessary or non-value adding and unnecessary.

PPA is also useful to compare a process with the other processes of similar projects. One can decide whether his/her process flows better or worse based upon the result of scaled value analysis. In addition, the PPA technique is a good and fast communication tool for construction personnel. Not only it makes people understand any processes easily by using the simple standardized symbols, but also it can be completed in a relatively short amount of time. For example, it took approximately five hours to analyze one process of the case studies, from measuring to making an improvement plan.

However, the research has specifically focused on the construction process of structural steel, which has highly repetitive works similar to manufacturing process. It is, therefore, necessary to ensure, through more case studies, that the PPA technique can be used for analyzing other kinds of construction processes. In addition, there is no explicit measurement of uncertainty in individual activity times at the fine level of detail. Neither is there an overt measure of flow in a PPA analysis, rather one must imply flow (or its absence) by evaluating waiting times.

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Appendix I. Flow Process Chart Example (Before Improvement)

Title: Erection (3 Beams)												
No.	Activities	answer y/n	Flow	Machine/ Tool	Distance (feet)	Crew Number	Crew Cost ($/min)	Time (min)	Bare Cost($)	Chart Symbol ○	□	⇨
1	Finding a member for erection		□			E-2	5.42				●	
2	hook-on hoist		○	crane		E-2	5.42	0.30	1.63	●		
3	Is there another member for lifting?	y	□			E-2	5.42				●	
4	Is the number of members less than the limit?	y(N)	□			E-2	5.42				●	
5	lift a member		⇨	crane	76	E-2	5.42	1.12	6.07			●
6	Does a member fit properly?	y	□			E-2	5.42	0.13	0.70		●	
7	Connect by minimum requirements		○	crane		E-2	5.42	1.63	8.83	●		
8	Unhook hoist		○	crane		E-2	5.42	0.38	2.06	●		
9	Is there another member for connecting?	y	□			E-2	5.42				●	
10	Return to lift another member		⇨	crane	76	E-2	5.42	0.48	2.60			●
11	Finding a member for erection		□			E-2	5.42				●	
12	hook-on hoist		○	crane		E-2	5.42	0.45	2.44	●		
13	Is there another member for lifting?	y	□			E-2	5.42				●	
14	Is the number of members less than the limit?	y(N)	□			E-2	5.42				●	
15	lift a member		⇨	crane	86	E-2	5.42	1.57	8.51			●
16	Does a member fit properly?	y	□			E-2	5.42	0.47	2.55		●	
17	Connect by minimum requirements		○	crane		E-2	5.42	1.28	6.94	●		
18	Unhook hoist		○	crane		E-2	5.42	0.27	1.46	●		
19	Is there another member for connecting?	y	□			E-2	5.42				●	
20	Return to lift another member		⇨	crane	86	E-2	5.42	0.23	1.25			●
21	Finding a member for erection		□			E-2	5.42				●	
22	hook-on hoist		○	crane		E-2	5.42	0.20	1.08	●		
23	Is there another member for lifting?		□			E-2	5.42				●	
24	Is the number of members less than the limit?	y(N)	□			E-2	5.42				●	
25	lift a member		⇨	crane	55	E-2	5.42	0.85	4.61			●
26	Does a member fit properly?	n	□			E-2	5.42	0.98	5.31		●	
27	Can repair be made without lowering?	n	□			E-2	5.42				●	
28	Remover/Lower		⇨	crane	55	E-2	5.42	0.77	4.17			●
29	Unhook hoist		○	crane		E-2	5.42	0.05	0.27	●		
30	Can repair be made?	n	□			E-2	5.42				●	
31	Can member be substitute?	y	□			E-2	5.42				●	
32	Finding a member for erection		□			E-2	5.42	0.05	0.27		●	
33	Hook-on hoist		○	crane		E-2	5.42	0.60	3.25	●		
34	Is there another member for lifting?	y	□			E-2	5.42				●	
35	Is the number of members less than the limit?	y(N)	□			E-2	5.42				●	
36	Lift a member		⇨	crane	55	E-2	5.42	1.05	5.69			●
37	Does a member fit properly?	n	□			E-2	5.42	1.07	5.80		●	
38	Can repair be made without lowering?	y	□			E-2	5.42	0.80	4.34		●	
39	Align holes		○	hammer		E-2	5.42	4.67	25.31	●		
40	Connect by minimum requirement		○	crane		E-2	5.42	0.68	3.69	●		
41	Unhook hoist		○	crane		E-2	5.42	0.28	1.52	●		
	Total		41 Act.		499			20.36	110.35	12times 10.79min	22times 3.50min	7times 6.07min
Notes	Before Improvement										Group:	
											By:	

Value added

Non-value added but necessary

Non-value added and unnecessary

Appendix II. Flow Process Chart Example (After Improvement)

Title: Erection (3 Beams)												
No.	Activities	answer y/n	Flow	Machine/ Tool	Distance (feet)	Crew Number	Crew Cost ($/min)	Time (min)	Bare Cost($)	Chart Symbol ○	□	⇨
1	Finding a member for erection		□			E-2	5.42				●	
2	hook-on hoist		○	crane		E-2	5.42	0.30	1.63	●		
3	Is there another member for lifting?	y	□			E-2	5.42				●	
4	Is the number of members less than the limit?	y	□			E-2	5.42				●	
5	Lifting to hook another member		⇨	crane	6	E-2	5.42	0.30	1.63			●
6	Finding a member for erection		□			E-2	5.42				●	
7	hook-on hoist		○	crane		E-2	5.42	0.30	1.63	●		
8	Is there another member for lifting?	y	□			E-2	5.42				●	
9	Is the number of members less than the limit?	y	□			E-2	5.42				●	
10	Lifting to hook another member		⇨	crane	8	E-2	5.42	0.30	1.63			●
11	Finding a member for erection		□			E-2	5.42				●	
12	hook-on hoist		○	crane		E-2	5.42	0.45	2.44	●		
13	Is there another member for lifting?	y	□			E-2	5.42				●	
14	Is the number of members less than the limit?	n	□			E-2	5.42				●	
15	lift 3 members together		⇨	crane	76	E-2	5.42	1.30	7.05			●
16	Does a member fit properly?	y	□			E-2	5.42	0.47	2.55		●	
17	Connect by minimum requirements		○	crane		E-2	5.42	1.28	6.94	●		
18	Unhook hoist		○	crane		E-2	5.42	0.27	1.46	●		
19	Is there another member for connecting?	y	□			E-2	5.42				●	
20	Lift members for another connecting		⇨	crane	10	E-2	5.42	0.23	1.25			●
21	Does a member fit properly?	y	□			E-2	5.42				●	
22	Connect by minimum requirements		○	crane		E-2	5.42	1.30	7.05	●		
23	Unhook hoist		○	crane		E-2	5.42	0.28	1.52	●		
24	Is there another member for connecting?	y	□			E-2	5.42				●	
25	Lift member for another connecting		⇨	crane	10	E-2	5.42	0.20	1.08			●
26	Does a member fit properly?	y	□			E-2	5.42	0.40	2.17		●	
27	Connect by minimum requirements		○	crane		E-2	5.42	1.20	6.50	●		
28	Unhook hoist		○	crane		E-2	5.42	0.27	1.46	●		
	Total		28 Act.		110			8.85	47.98	9times 5.65min	14times 0.87min	5times 2.33min
Notes	After Improvement										Group:	
											By:	

Value added

Non-value added but necessary

Non-value added and unnecessary