

Towards zero-process waste through supply chain integration in steel construction

Cómo lograr procesos con cero pérdidas a través de la integración de la cadena de suministros en las construcciones de acero

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PAG 75-82

Abstract

CPM and PERT are well established as the main tools to plan and control construction projects. However, the planning and control of construction field operations has to consider the minute-by-minute complexity of bringing multiple resources together to produce a work package. At this level, the quality of each resource has major effects on the productivity, quality or safety. The rapidly changing dynamic nature of the site and the shifting quality of critical factors requires a new model to achieve zero-process waste. This paper presents a new construction management model that embraces a waste-based feed-forward control methodology designed to eliminate process or muda-waste rather than high productivity. It extends the concept of the seven mudas by Taiichi Ohno to include all construction specific wastes. Of special interest of the discussed work is the waste effect of poor communication along the supply chain. After discussing the rationale of the model the paper highlights the results of field observations in the area of foundations and steel construction. Wireless cameras were used for continuous-time studies to measure productive and wasted labor-hours before and after changes in the material supply logistics were implemented.

Keywords: Zero waste, feedforward control, supply chain

Resumen

Los métodos CPM y PERT se encuentran bien establecidos como la principal herramienta de planificación y control de proyectos de construcción. Sin embargo, la planificación y el control de operaciones de construcción en terreno tienen que considerar la complejidad del día a día de utilizar múltiples recursos al mismo tiempo para elaborar un paquete de trabajo. A este nivel, la calidad de cada recurso tiene grandes efectos en la productividad, calidad o seguridad. Los rápidos cambios debido a la naturaleza dinámica en terreno y los cambios de calidad de los factores críticos requieren de un nuevo modelo para conseguir procesos con cero pérdidas. Este documento presenta un nuevo modelo de gestión de construcción que aprovecha la metodología de control por prealimentación basado en el desperdicio, diseñado para eliminar pérdidas o muda en los procesos en vez de aumentar la productividad. Éste amplía el concepto de los siete mudas de Taiichi Ohno que incluye todos los desperdicios específicos del proceso de construcción. De especial interés en el trabajo es el efecto del desperdicio por una mala comunicación a lo largo de la cadena de suministro. Después de discutir la lógica del modelo, este estudio presenta los resultados a partir de observaciones en terreno de las fundaciones y la construcción en acero. Se instalaron cámaras inalámbricas para realizar un estudio de tiempo continuo a fin de medir productividad y pérdidas de horas de trabajo, antes y después de implementar los cambios en la logística de la cadena de suministro.

Palabras clave: Cero pérdidas, control por retroalimentación, cadena de suministro

1. Introduction

What is today known as Building Information Modeling (BIM) started with researchers like Charles Eastman (1975) in the early 1970's, first recommended and supported as an industry standard by the National Institute of Building Sciences in Washington, DC in the late 1980's is only now accepted as a global standard. The drivers such as interoperability, automatic interference checking and digital communication are now able to overcome the industry's traditional reluctance to change. Still, researchers have pointed out that BIM is only a stepping stone enabling benefits that will dwarf the present to the industry.

It is estimated that the construction industry consumes about 40% of the world raw material and has become a truly global market with a complex supply chain of processed and prefabricated material and entire building elements. On the other hand, construction contributes 40% of the carbon emissions to the atmosphere (e.g., cement production) to and

creates a massive stream of material waste that end up in landfills. However, physical waste is only the most visible sign representing its inefficiency. Smith, D. K. and Tardif (2012) reported the Construction Industry Institute (CII) estimated that up to 57% of the construction work is non-valued adding or waste of any process resource including idle time or repair of poor quality outputs. This large number compares poorly to the 26% inefficient use of resources in manufacturing. An early proponent of eliminating process waste in manufacturing was Toyota's Chief Engineer, Taiichi Ohno, as a key element of the Toyota Production System (Bernold and AbouRizk, 2010, Bernold 2013). Termed "Muda" (waste or without value in Japanese) he defined 8 groups of muda in car manufacturing: 1. Overproduction, 2. Excess Inventory, 3. Unnecessary Motions, 4. Idle Waiting, 5. Unnecessary Transportation, 6. Inefficient Processing, 7. Defects, Breakdowns, Injuries, and 8. Non-used Employee Talent.

In the late 1980's Muda waste was included in the concept of Lean Manufacturing which was later adopted as a Lean Construction. As manufacturing was forced to expand its

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managerial methods to create global production networks, implementing lean thinking selectively. Lean Construction has failed to provide a coherent theoretical concept. Similarly there exist no scientific evidence about its proven benefits and the literature consists of many qualitative descriptions. Presently, lean construction is a random accumulation of (reactive) tools that were developed in manufacturing such as Just-in-Time, (JIT), six-sigma, or Total Quality Management (TQM). While TQM (ISO 9001) implies better quality for less money, Rosenfeld (2009) presented the failure of this short sighted outlook of the industry focusing on hiring a quality manager with staff and more inspections. Rosenfeld (2009) showed that the lower cost for repairs equaled the cost of additional staff. Forslund (2007) summed up the present situation highlighting that, "...instead of focusing on improving quality, reducing quality deficiencies is the objective." Bellah et al. (2013), reminded us that: "TQM is a philosophy and set of practices that aim to eliminate all forms of waste from all product manufacturing and service delivery processes."

2. A philosophy of zero-process waste

For centuries the construction industry is asked to predict the completion time and the final cost of building projects one or even two years ahead. Again and again companies fail in predicting either. Bernold and Abourizk (2010), argued for a new management philosophy for construction that builds on real-time control. The new thinking depicted in Figure 1 is based on an old concept, proactive management, but provides it the necessary

theoretical underpinning and tools to implement it in construction, considering an intelligent construction job site.

New technologies as a sensor will supply the needed data in real time from smart controllers to detect problems. Indeed, the unified and single objective to enable the proactive Zero-Waste control model. Figure 1 highlights that the feed-forward control covers even the supply chain. The necessity of inspections to evaluate the quality or even to repair what has done incorrectly, will be replaced by a holonic planning and control concepts that covers the entire supply chain until completion and operation. Implementing successful Zero-Waste management concepts will allow achieving the maximum possible productivity, desired quality including safety concepts.

2.1 Principles of feed-forward control for zero-process waste

Figure 2 presents a more detailed view of the process control model for one process that is integrated with the supply chain as the steel construction process discussed in the following chapter. The model indicates the two sources of feed-forward data and information, the supply chain and the staging area on site.

Furthermore, the information flows from the process controller reach the same locations. It is apparent the goal of the process controller is the preventive waste management through the elimination of causes in the input stage that could result in a waste. As indicated, this concept includes the supply-chain as many important decision made during the early phases can have drastic negative impacts (e.g., constructability).

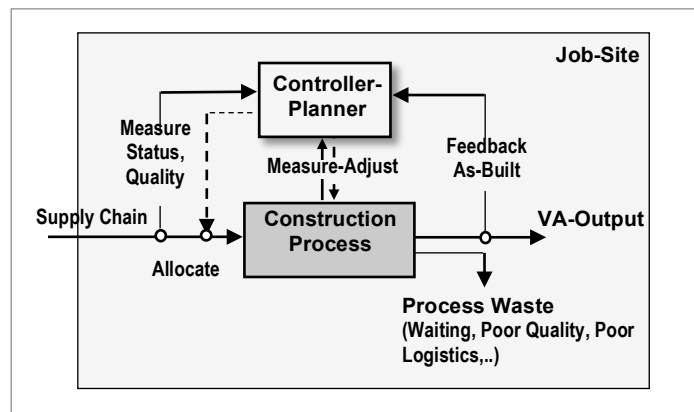


Figure 1. Zero-waste control structure with feed-forward control

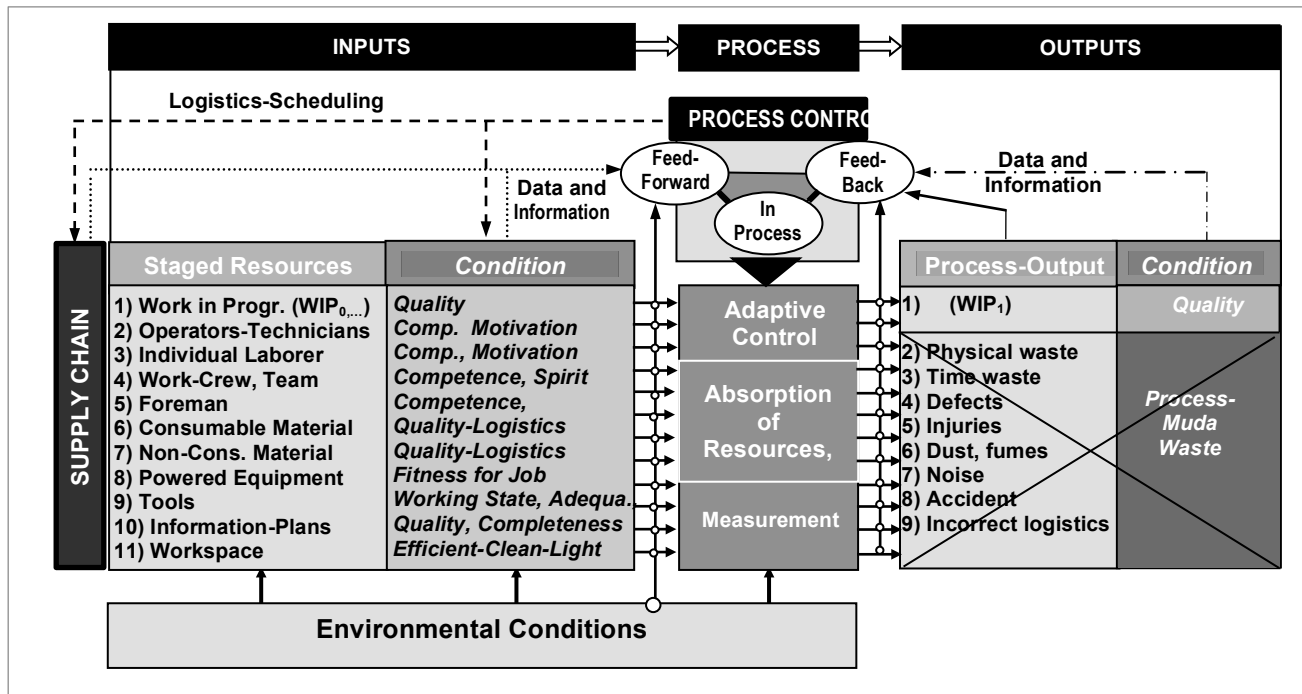


Figure 2. Model of preventive feed-forward control zero-process waste

3. Understanding causes of process waste

Published work on the study and scientific measurements of process waste is sparse. Recently, several papers focused on rebar and concrete operations (Moon et al., 2015; Moon and Bernold 2013; Zekavat et al., 2014). Totally inappropriately, the paper in 2015 published by the Journal of Construction Engineering and Management (JCEM) was considered a Case-Study despite the fact that active experiments with different supply-methods were reported. The following section of the paper presents the results of a project to identify and quantify the “muda-waste” during the construction of a steel structure to be used as storage facility on an approximately 13.000 m² large site.

3.1 Project overview

The design for the large single story consists of the traditional elements: a) concrete foundations with anchor plates for, b) steel columns supporting c) wide-span I-beams for the roof. The panels for the concrete foundations and walls are pre-fabricated at a central location on site by a carpentry crew and stockpiled (see Figure 3a) to be used by the forming crew. The structural steel is designed using BIM software that is integrated with the steel milling and cutting machines. The steel elements are welded and loaded on supply trucks (see Figure 3b) which transports everything, including the bolts and nuts, to the close-by site where the articulated truck-mounted crane is employed to unload. When the concrete foundations are ready, columns are installed and a bay of two beams is assembled on the ground (Figure 3b₃) and lifted into place by two cranes.

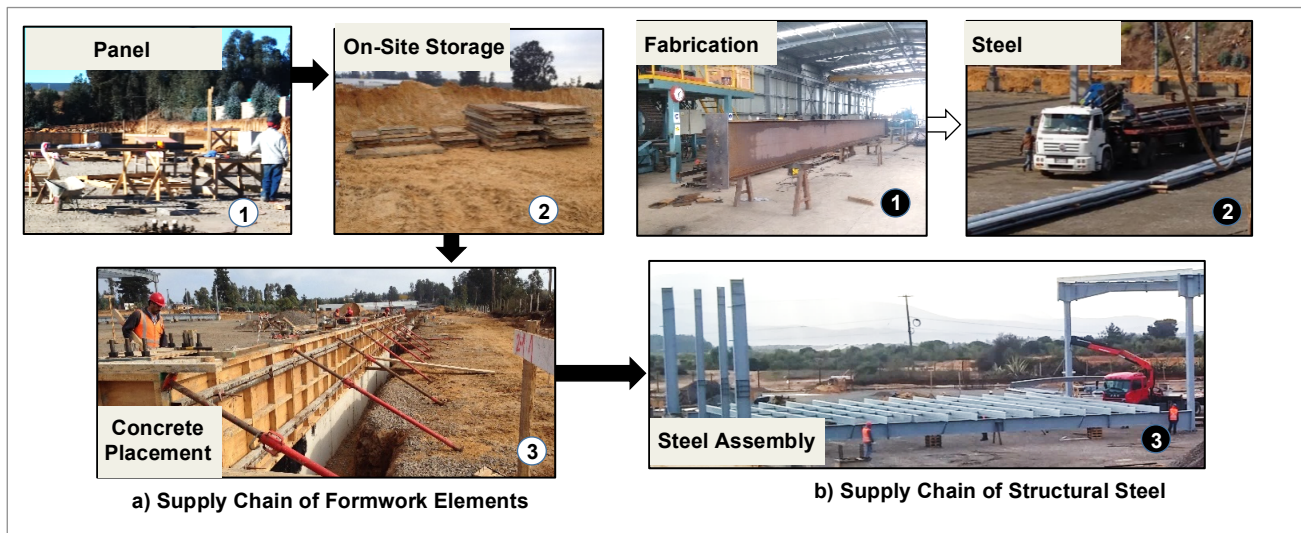


Figure 3. Supply chains for concrete foundations and structural steel



The sequence of steel erection dictates the sequence of the concrete operation and with it the prefabrication of the concrete form panels and the installation of rebar for the foundations. Because of its importance, the decisions on the sequences are made during a joint meeting between engineers from the design office, and the managers of construction and steel fabrication. The design office presents a process that is based on BIM modeling to achieve structural stability during construction. Then construction manager plans for the appropriate resources (hires workforce, materials, tools, renting of large equipment, etc.) Finally, the fabrication manager establishes the order of fabrication to satisfy the sequence of steel erection. All plans need to be approved by the general managers.

3.2 Preliminary observations to identify cause-effect relationships

Before designing a measurement system, an extensive observation study was initiated in order to define the most critical factors that contribute process waste. Utilizing the

time-lapse and personal observation methods, the ongoing work was studied. The immediate goal was to establish a list of activities and tasks while categorizing them into productive, supportive or non-productive. In a second phase the causes for the non-value adding work were identified. Figure 4 depicts the result of this phase in the form of a fishbone diagram showing the most critical causes.

It is apparent that the identified causes are in line with previous studies (Bernold and AbouRizk, 2010, Moon et al., 2015). Several factors are related to bad or non-existent planning of the supply logistics (e.g., steel laydown area far from place of use). A second set is clearly related to poor or non-existing communication (e.g., waiting for instructions).

While observing the field work it became clear that many processes were cyclic in nature offering the opportunity to apply statistical methods for the analysis. The first step was to model the processes as flow-diagrams. Figure 5 presents the model for the very important steel assembly process for a section of the steel roof.

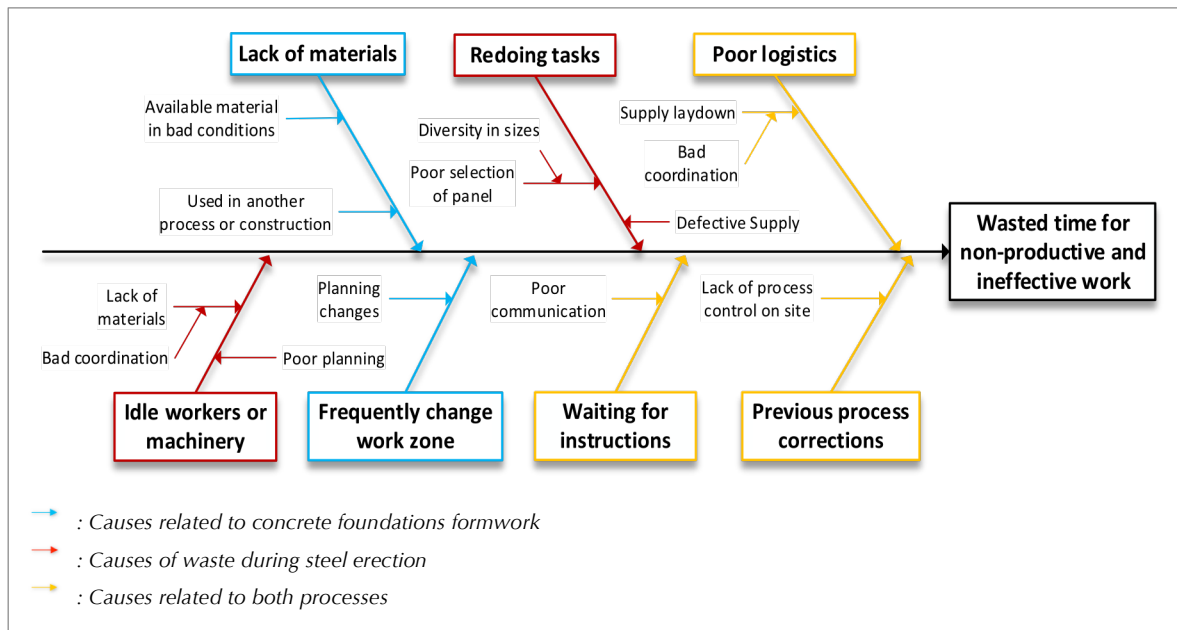


Figure 4. Fishbone diagram of observed causes leading to time-wastes

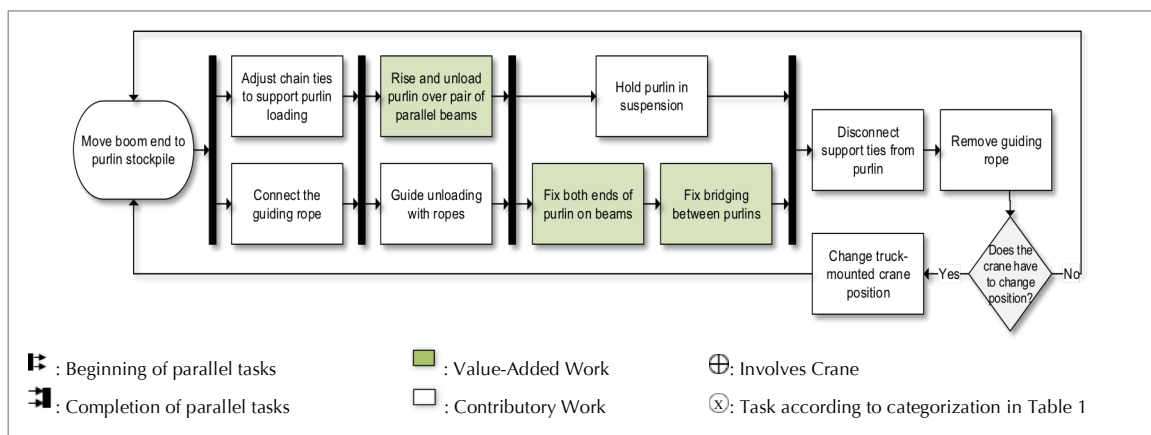


Figure 5. Process model of assembling one steel roof section on the ground (Figure 3 b₃)



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It is mandatory for the truck-mounted crane to be controlled by a qualified operator, because this delicate work requires previous certified training based on regulations. The delivered service by the truck-mounted crane and operator is requested to an external company (a subcontract) and, as such, it includes a certified operator. The operator has the only mission to control the truck-mounted crane according to the instructions indicated by the manager on site about the work to be done every day.

4. Installation of a field observation system

In order to ensure a continuous observation of the operation it was decided to install two wireless IP cameras at different locations. The goal was to cover the larger field via

video that would capture the process for later analysis. As a consequence two wireless cameras were installed at the long ends of the field (133 m x 97 m). Camera 1 was positioned 15 m off the corner and 7 m above the site level could be powered by an electric extension cable. Camera 2, located at the other end of the field could not be serviced with electric power and thus was powered via a deep cycle battery of 75 Ah and an inverter. To conserve energy and extend the life of the battery a digital timer was used which resulted that the battery had to be charged only once per week. The timer turned the power off during non-work hours.

As shown in Figure 6 Camera 2 was mounted on top of a pole while the power supply system was locked into a box and attached to another pole. Connectivity to the WiFi router, 154.0 m from the camera, was sufficient as long as no obstacles were interfering the line-of-sight.

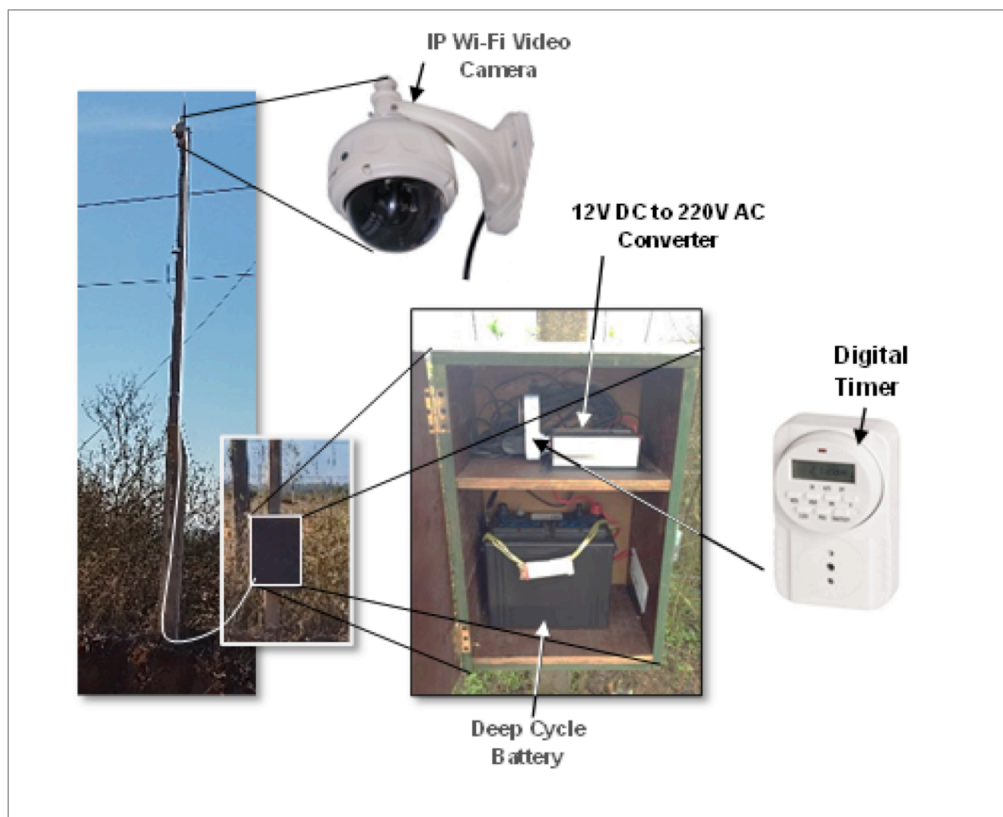


Figure 6. Battery powered observation station with long distance Wi-Fi connection



5. Design and evaluation of continuous time study data

Both operations presented in Figure 3, concrete foundations and steel erection, were observed in order to collect process data. The objective of this phase is to provide statistically sound data that verify the qualitative observations that led to the fishbone diagram shown in Figure 4. The resulting data about identified process-waste are discussed.

5.1 Comparative evaluation of process-waste

The concrete foundation contractor was willing to implement recommended changes after the detailed field study confirmed that the time-waste due to the lack of planning and stockpiling the formwork panels and other material observed earlier. Figure 7 presents the result of eliminating causes of wasteful activities such as walking empty handed to procure material as a change in average labor-hours/installed formwork panel. Thus, the shown drops are combinations of an elimination of wasteful work as well as increased efficiencies.

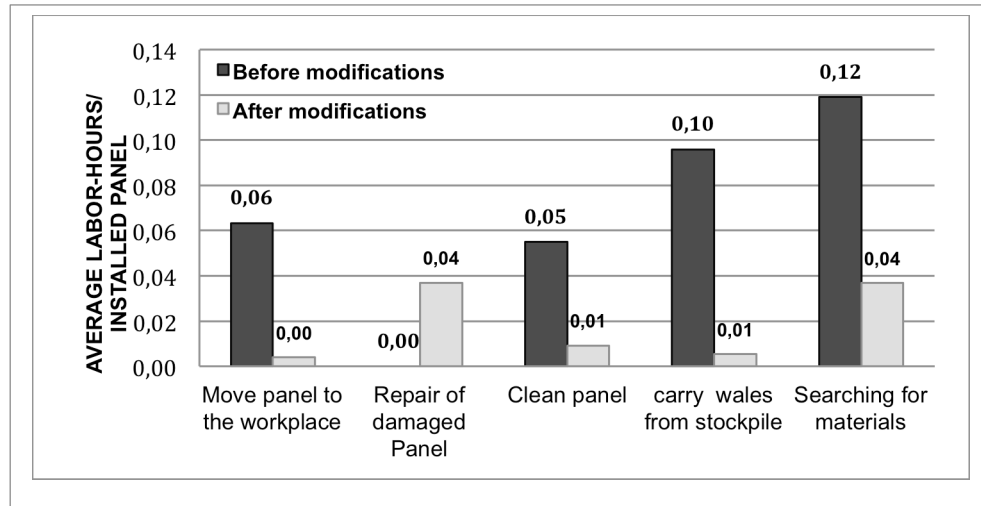


Figure 7. Comparison of time efficiencies before and after material logistics planning

As depicted in the graph, the effect of the implemented changes in the supply chain was very drastic. For example, in average the time to get a panel dropped from 0.06 to 0.005 labor-hrs/panel. Even larger improvements were made when wasteful time to collect the horizontal wales, dropped from 0.1 to 0.01 labor-hrs/panel, and for searching material from 0.12 to 0.04 labor-hrs/panel. The only increase in time was the result of some damaged panels that had to be repaired. In summary, the preventive planning of the panel supply logistics not only reduced the work on waste producing activities by 67% but, equally important, the average time for installing one panel was shortened from 71.2 to 28.8 min/installed panel.

5.2 Continuous-time study of steel erection process

This method to measure the amount productive- and non-productive time spent on a process was described in Bernold and AbouRizk (2010). As described earlier, time-

lapsed images of the work was captured using two wireless internet cameras and subsequently analyzed. However, the first step was to break down the work into the predefined categories as: 1) Value Added, 2) Contributory, 3) Ineffective, 4) Unproductive, and 5) Personal. Figure 8 presents the assignment of 18 tasks to the 5 categories used to process the 69 cycles of steel purlin installation representing a total of 22.24 hours of work.

The time used by 8 to 10 laborers is kept separate from the crane-operator time and the first results are shown in labor-hrs, as the number of laborers working on one task is changing randomly. One easily recognizes the significant amount of unproductive time used by both the crane-operator, 11.7 hrs/69 cycles and the laborers, 7.74 labor-hrs/69 cycles while the average time for carrying purlins closer to the place of assembly amounts to 2.4 labor-hrs/69 cycles.



Task Category	Task Content	Resources Involved	69 Cycles (22.24 hrs)		Wasted Labor Time	
			Labor-Hrs	Crane-Hrs		
Value Added	1) Lift and place one purlin element	Crane+Oper	33.39	2.83		
	2) Fix both ends of purlin on beams	2 Laborers				
	3) Fix bridges between purlins	3 Laborers				
Contributory	4) Crane holds purlin in place	Crane+Oper	14.36	8.57		
	5) Adjust slings	2.5 Laborers				
	6) Connect guide rope	1 Laborers				
	7) Guide purlin with rope	1.1 Laborers				
	8) Remove slings	2 Laborers				
	9) Remove guide rope	1 Laborers				
	10) Truck crane changes position	Crane+Oper				
	11) Crane boom slews to stockpile	Crane+Oper				
Ineffective	12) Carry one purlin from stockpile	3.5 - 8.0 Laborers	2.40	0.00	3.2%	3.2%
Unproductive	13) Correct wrong beam position	4 Laborers	7.74	11.70		24.8%
	14) Fix already installed purlin	5 Laborers				
	15) Truck crane waiting in the morning	Crane+Oper				
	16) Crane idle as crew called away	Crane+Oper				
	17) Crane idle as crew gets instructions	Crane+Oper				
Personal	18) Special rest time	Laborers	2.67			

Figure 8. Breakdown of steel assembly work with basic average data

An astounding 28% of the total labor-hours of “muda” waste is calculated while the crane and operator stay idle for over 50% of the time mostly because the crew is been called away by the manager to unload another steel truck or to provide instructions.

6. Summary and conclusions

How well a system is able to perform as a whole depends on the quality of each individual part as well as the skill to coordinate them most efficiently. As many disasters demonstrate again and again even one element of bad quality can result in the destruction of the entire system. ISO 9000, originally published in 1987, was the first approach to certify entire construction companies on their capability to maintain high quality and to conform to a standard. The premise was that an ISO 9000 certified company would produce high quality products or services. On the other hand, Gotzamani and Tsiotras (2001) found that the most important contribution of implementing ISO 9000 is the emphasis on “process management.” However, reports after reports tell us that the construction industry is not adopting those essential principles that would lead to major improvements (Sullivan 2011).

This paper argues that the key obstacle for the industry to adopt TQM is its outdated concept of process control which relies on feedback inspection and repairs. The lagging productivity of the industry is evidence that the industry needs to change. The work discussed here is based on a method for planning and control methodology that is preventive in nature applying feed-forward control of resource quality in order to avoid poor quality. To test the effectiveness of this new philosophy a field study was performed focusing on concrete foundations and steel erection. The main objective was to measure the effect of the traditional construction supply chain which is characterized as a series of sequential operations by short-term project

members with a “zero-sum” game attitude. Utilizing two wireless IP-video cameras the continuous-time study method were applied to quantify productive as well as waste-full unproductive time (process-waste) spent by the laborers and one truck crane. In addition, the effect of logistics planning was assessed. The latter demonstrated in a drastic manner the potential of a preventive zero-waste philosophy in that time spent on unproductive tasks was reduced by 67% indicating that still more can be done. At the same time, the average time to install one formwork panel was reduced by 60% mostly by eliminating time needed for carrying and searching for forming material. It is evident that these incredible values can be further improved.

Observing and measuring the assembly of steel roof sections on the ground resulted in similar outcomes. Here, 28% of labor-hours for assembling 69 purlins was unproductive and ineffective while the crane and its operator were idle 50% of the time.

Similar to previous studies on feed-forward control in construction, the still ongoing project provides numeric evidence that embracing the managerial approach of zero-process waste will not only eliminate the cost for fixing poor quality after inspection but, without adding cost, will lead to drastic productivity improvements in construction.



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