Steel Construction Processes Modeled Using Simulation Technology

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Steel construction is considered as a process that involves many related activities. Pre-engineered buildings (PEB) steel parts are required to be installed in a specific order due to structural safety requirements and due to the logical sequence of erection. They require repetitive operations and assembly of many structural elements. However, shipping, transportation, unloading and on-site storage do not take into account the erection order of the assembly. As a result, considerable time is consumed in locating, sorting and identifying steel components. Consequently, a need for advanced tools and techniques to study, plan, and manage the steel processes need to be proposed. In order to clearly present the mentioned problem, a steel construction project is used as an example to represent an overview of the current practices of existing steel construction operations, to identify potential productivity problems and sources of waste, and explore the potential possibilities for improving current processes. Installation procedure is carefully evaluated to develop the initial process model. Information flow diagram for Pre-Engineered process from shipping the steel materials to erection on the construction site is developed. Then a simulation study is conducted using web-based Micro Cyclone simulation software to determine the current duration of one cycle of steel processes. Finally, improvements in the steel process are proposed to represent a future application in the steel construction industry.

KEYWORDS: Micro Cyclone, Pre-Engineered Building, Productivity, Simulation, Steel Structures

Introduction

During the construction phase of a project, it is essential that the information flow is smooth and continuous throughout the process. Field supervisory personnel on construction site spend between 30% - 50% of their time recording and analyzing field data (McCullouch 1997) and 2% of the work on construction sites is devoted to manual tracking and recording of progress data (Cheok et al. 2000). In addition, since most data items are not captured digitally, data transfer from a site to a field office requires additional time. When the required data is not captured accurately or completely, extra communication is needed between the site office and field personnel (Thorpe and Mead 2001). These extra efforts are time consuming and waste resources. These inefficiencies are embedded and distributed among different activities and project participants, and hence, the project team is not aware generally of the implications and aggregate time and money waste associated with them. Pre-engineered buildings (PEB) steel parts are required to be installed in a specific order due to the logical sequence of erection. Thus, in standard steel construction practice, construction designers make decisions regarding the construction processes. These decisions include construction methods, selecting equipment and planning operations. In some situations, decisions are made with unexpected outcomes. In real life situations, testing a construction method is very expensive and time consuming. However, simulation is a convenient technique to model real-life construction operations (Zayed et al., 2000). A model is a representation of real-world situation to provide a framework within which a given situation can be investigated and analyzed. The whole steel construction process from fabrication to shipping and erection are described in the following section. Key materials brought in during each phase of the steel construction process are briefly described in order to model the existing steel construction processes.

Steel Construction Process Overview

Preplanning and Fabrication

At an early stage, the general contractor and the steel supplier work together to discuss project site constraints. In addition, they determine the steel erection sequence, i.e. the order in which a zone or section of the structural steel frame is delivered and erected to improve the efficiency of loading, delivery, unloading and erection. Based on the requirement of the general contractor master schedule and the fabricator load schedule, the steel factory generates the fabrication and shipping schedule.

Shipment and Unloading

Often, due to space limitation, the fabricated steel members can not be immediately shipped to the construction site, but are stored in storage pending erection sequence. Upon delivery to the jobsite, receiving and unloading of materials should take place as near as possible to the place of erection. The lay-down area should be clean and leveled. A 3-ton forklift truck is ideal for unloading, but a mobile crane is equally suitable. After unloading, the steel pieces are organized in such a manner to erect the structural components efficiently.

Steel Erection

The major components of the structural system are comprised of rigid frame, columns and rafter, eave struts, purlins, girts, flange braces, end-wall columns, bracing systems such as cables, rods, angles or portals. All materials for the first bay erection are prepared. The rafter sections required are identified by part number, and then assembled as close as possible to their lifting positions. Then the first four columns are erected at the braced bay, meanwhile the part number and orientation, and position over anchor bolts were verified. Next step is to position the crane for lifting the assembled rafter sections.

Model the Existing Steel Construction Processes

Based on field observations, a diagram of materials and information flow is formulated to represent the flows of information and materials throughout the fabrication, shipping, and erection phases. Experience and interviews with key players are used to model the existing processes (Ghanem et al. 2007). This diagram provides a guideline of what information the steel crew needs to perform a specific task, how data is shared, and where to get those data from. This helps diagnose existing PEB steel construction processes to find out alternative processes. Figure 1 presents the materials and information flow of the PEB steel construction processes. As seen in the diagram, information and materials are passed from one party to another via conventional approach. Key data sources within the defined system are: fabricator, worker, foreman, and site manager. The next section presents the simulation models and defines the productivity of the current practices and need for improvement.

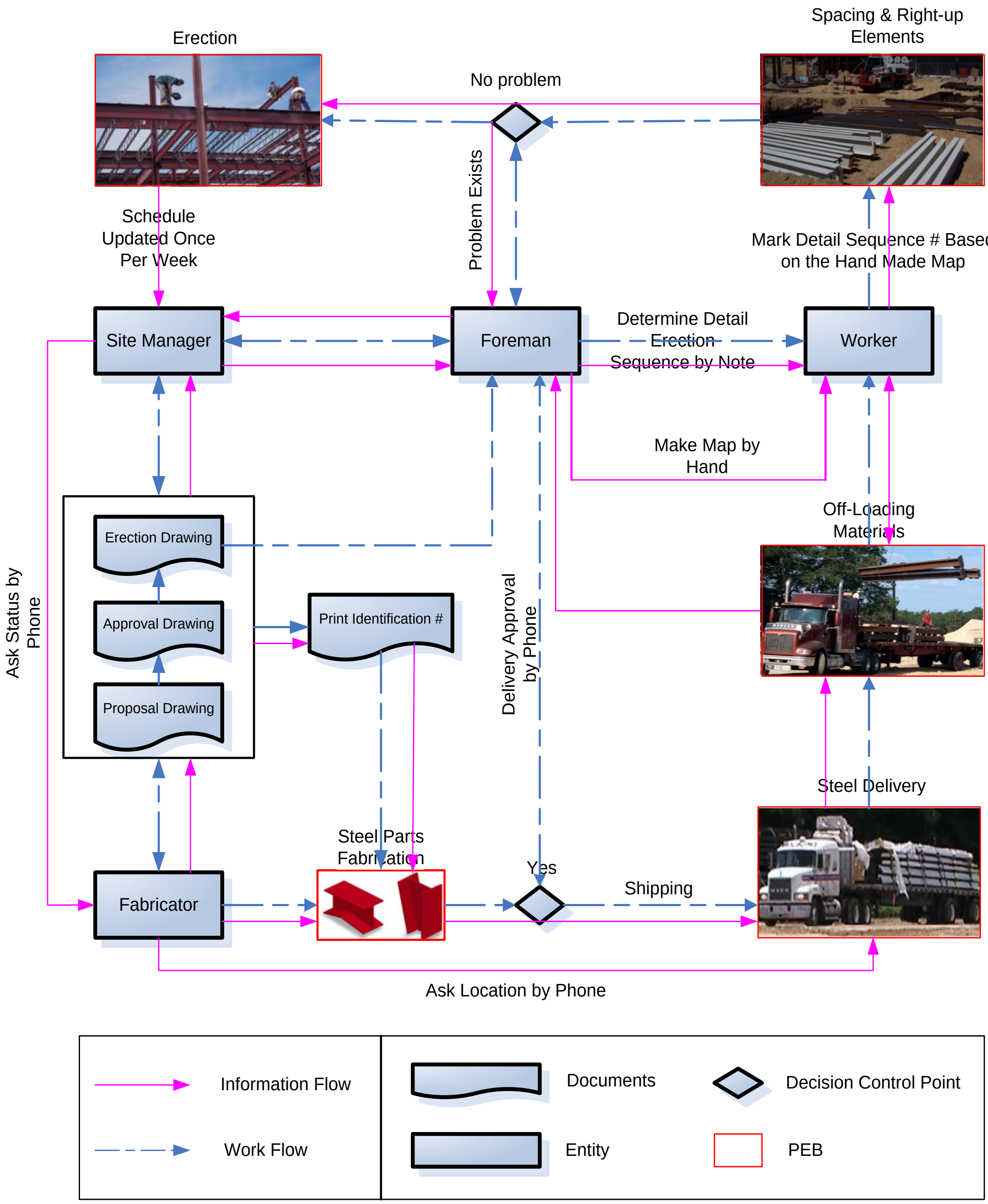


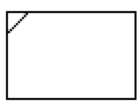
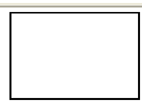
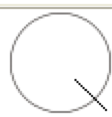
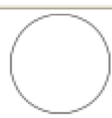
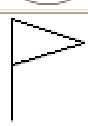
Figure 1 Materials and Information Flow

PEB Simulation Model

Micro Cyclone

One of the first and best known simulation languages specifically designed to investigate the use of simulation networks for modeling construction operations and activities is CYCLONE (Cyclic Operations Network) (Halpin, 1977). The Cyclone system has been used frequently to model construction processes because of its ability to provide a quantitative way of viewing, planning, analyzing, and controlling the processes and operations. Micro Cyclone is a microcomputer-based program designed to run Cyclone simulation models. It is used in this study in order to investigate the steel construction processes. The elements of Micro Cyclone, originally developed by Halpin (as shown in table 1), are used to model and simulate PEB steel operations (Halpin and Riggs, 1992).

Table 1 Basic Modeling Elements of Cyclone

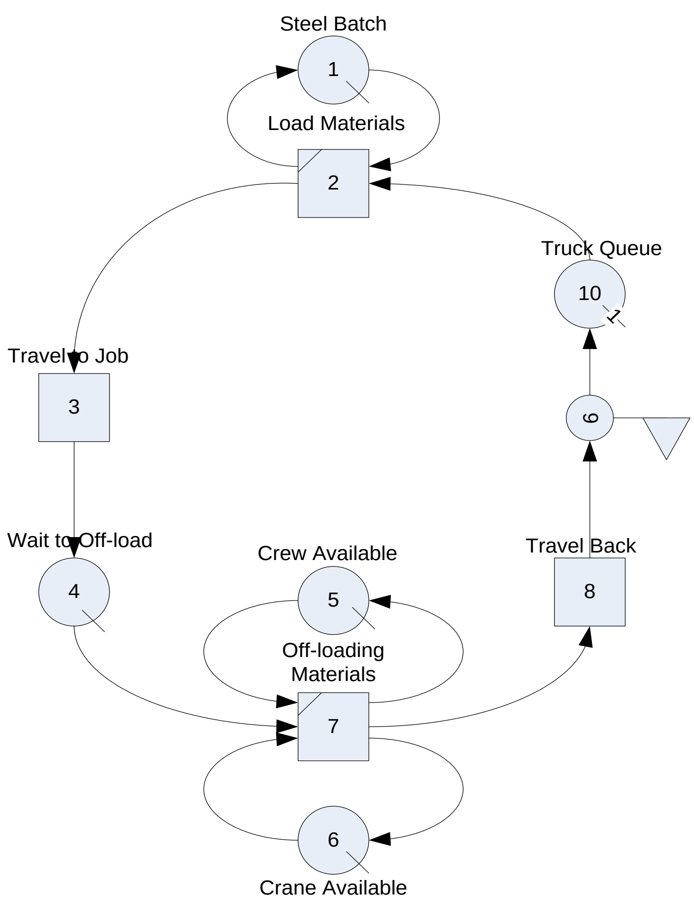
Name	Symbol	Function
Combination (COMBI) Activity		This element is always preceded by Queue Nodes. Before it can commence, units must be available at each of the preceding Queue Nodes. If units are available, they are combined and processed through the activity. If units are available at some but not all of the preceding Queue Nodes, these units are delayed until the condition for combination is met.
Normal Activity		This is an activity similar to the COMBI. However, units arriving at this element begin processing immediately and are not delayed.
Queue Node		This element precedes all COMBI activities and provides a location at which units are delayed pending combination. Delay statistics are measured at this element
Function Node		It is inserted into the model to perform special function such as counting, consolidation, marking, and statistic collection
Accumulator		It is used to define the number of times the system cycles
Arc		Indicates the logical structure of the model and direction of entity flow

(Source: Halpin and Riggs 1992)

Simulation Model

The formulated model takes into consideration the delivery and the availability of the steel parts on the construction site. In addition, in case there was a problem with erection or with the steel parts, there is a two way communication between the construction site and the steel fabricator. Based on a trial and error procedure, and by trying different simulation models, the authors decided to separate the shipping process from the erection simulation process, since the shipping process takes more time than the erection process and thus placing both processes into one simulation model yields inaccurate results.

Figure 2 and Figure 3 present PEB steel simulation model for both shipping and erection. The shipping model is comprised of 10 entities covering one cycle of the process. The cycle starts from loading the materials at the fabricator shop to the offloading of the material on the construction site. The erection model is formed of 30 entities each covering one cycle of the process. The cycle starts from steel parts available on the constructions site to erection of one bay of the steel structure. Once the graphical model is established, the next step is to transform it into an input language compatible with the Micro Cyclone (Ghanem, 2007). Durations and resources were also incorporated in the input file. Some entities representing inefficiency in the processes were included in the model. Familiarity with the Cyclone program makes the transition from graphical input to computer language the simulation software an easy step. Web Cyclone is case sensitive and all typing should be done in upper case letters. As noticed in the output model, some resources are idle while others are in use. The next section discusses those entities since they represent an opportunity for improvement of the steel processes, increase efficiency and minimize waste.

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NAME STEEL SHIPPING LENGTH 1000 CYCLES 30
NETWORK INPUT
1 QUE 'STEEL BATCH'
2 COM SET 1 'LOAD MATERIALS' FOL 1 3 PRE 1 10
3 NOR 'TRAVEL TO JOB' SET 2 FOL 4
4 QUE 'WAIT TO OFF-LOAD'
5 QUE 'CREW AVAILABLE'
6 QUE 'CRANE AVAILABLE'
7 COM SET 3 'OFF-LOAD MATERIALS' FOL 5 6 8 PRE 4 5 6
8 NOR 'TRAVEL BACK' SET 4 FOL 9
9 FUN COU FOL 10 QUA 1
10 QUE 'TRUCK QUEUE'
 DURATION INPUT
SET 1 NOR 3 1
SET 2 NOR 7 2
SET 3 NOR 1.5 1
SET 4 NOR 7 2
RESOURCE INPUT
1 'STEEL BATCH' AT 1
3 'TRUCK' AT 4
1 'CREW' AT 5
1 'CRANE' AT 6
6 'TRUCKS' AT 10
ENDDATA
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Figure 2 Shipping Simulation Model

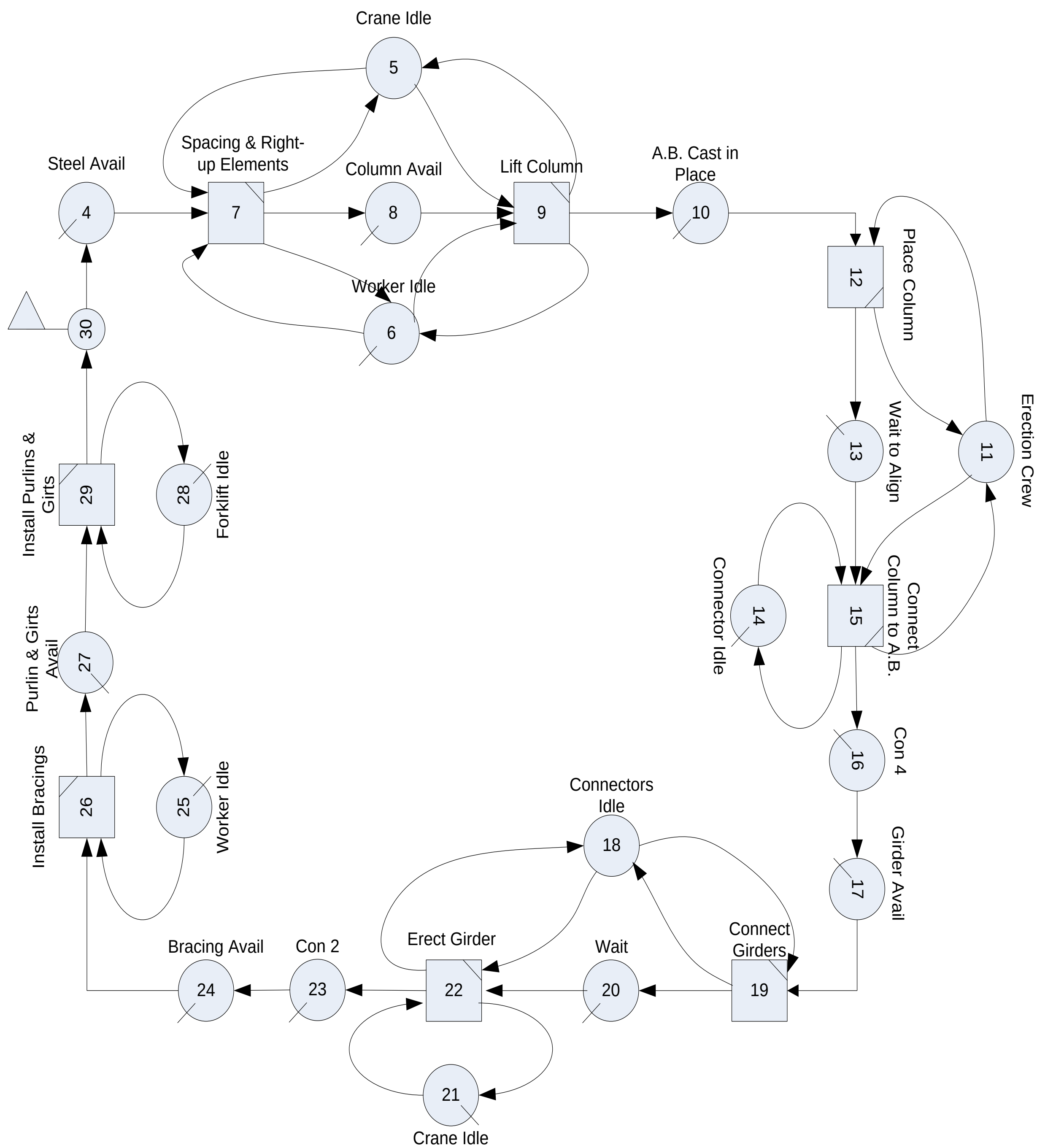

Figure 3 Erection Simulation Model

Simulation Outputs

The main output of the simulation that is presented in this paper is the productivity result, which shows the number of cycles per unit duration as shown in Figure 4. This productivity data can be used to evaluate the performance of a process design at a glance. In addition, the site engineer can use the sensitivity analysis function to try to improve the productivity of a process by changing the resources. Based on Web Cyclone, the construction simulation result of a repetitive cycle in the project under study is presented as the productivity. For computing productivity of both shipping and erection process, 'Hours' was used as the time unit as shown in Table 2.

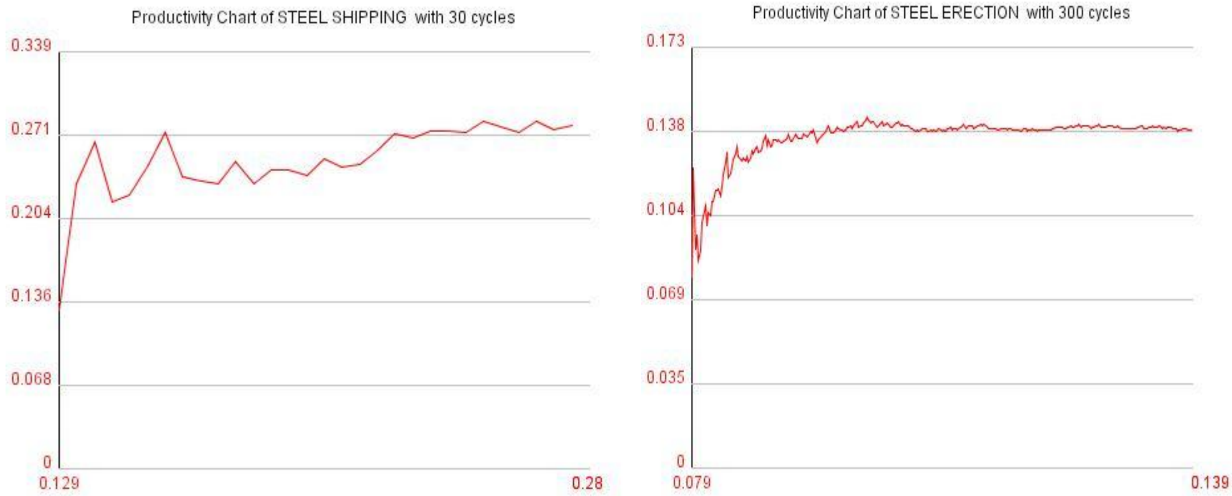

Figure 4 Simulation Output

The cycle number in Table 2 represents the amount of time both systems cycle. For instance, one cycle of shipping steel materials (Refer to Figure 2) includes Queue node (1: Steel batch) to Queue (10). In case of erection process (Refer to Figure 3), Queue node (4: Steel Available) to accumulator (30) is included in the one cycle of the system. It is defined by user. Therefore, the productivity of shipping can be calculated through dividing 'Cycle number' by 'Total simulation time (i.e., 30/107.3 = 0.279) and 300 / 2155.9 = 0.139 for erection).

Table 2 Simulated Productivity Results

	Total Simulation Time (unit)	Cycle No.	Productivity (per time unit)	Production/Cycle	Productivity
Shipping	107.3	30	0.279	1 truck	0.279 truck per hour
Erection	2155.9	300	0.139	1 bay	0.139 bay per hour

Based on the simulated productivity table, it takes 3.58 hours in order for one truck to reach the construction site. At the same time, it takes 7.19 hours to erect one pre-engineering steel bay.

As noticed in the output model example (Appendix A), some resources are idle for a short period, others for a long period, while others are in use. The next section discusses those entities, the reasoning behind them as they represent an opportunity for improvement of the processes, for increasing efficiency and minimizing waste.

Process Inefficiency

PEB steel parts are required to be installed in a specific order due to structural safety requirements and due to the logical sequence of erection. However, shipping, transportation, unloading and on-site storage do not take into account the erection order of assembly. As a result, a considerable time is consumed in locating, sorting and identifying steel components. Instead of setting the steel directly off the delivery trucks, all the steel is off loaded and shakeout is done as the steel is delivered. This practice results in double handling of materials in the erection operations.

Once fabricated, the fabricator labels each steel member with a unique piece mark and sequence number to identify it directly on the erection drawings and its proper placement. However, to make it easy to find materials for erection, the workers mark each piece one more time with white chalk based on the erection hand map. This process leads to considerable unproductive duplication.

Another concern is raised when workers try to locate the exact material to be erected. The foreman determines the exact order in which each steel member has to be erected. Workers identify components with paper-based information. As a result, a significant portion of time is spent in the lay-down areas searching to identify components.

During the interview at the construction site, it was found that material and information flow can be lost, disconnected and distorted while flowing from information sources to end user. Good examples were sited to the author. Workers didn't know when the next shipping date is scheduled. Connectors did not have a clear idea of where each steel element was positioned. The foreman had no idea of the status of a shop drawing approval after implementing some changes and which sequence of steel elements were fabricated and stored at the factory and ready to be shipped.

Other communication problems were identified with the current process such as the approval of drawings and request for information. Usual delays associated with the steel supply process are encountered during approval stage of shop drawings. Weeks are wasted due to the movement of hard copy drawings from one party to another.

Another major delay at the jobsite is a problem that can not be resolved at the field office, so the site engineer has to submit a request for information (RFI) to the technical engineering department. RFIs are sent via fax with a sketch and a reference to the drawings. In case photos were needed or attached, they have to be mailed. This would delay RFI turnaround times.

Discussion and Conclusions

A significant number of problems were identified resulting from inaccurate data transfers as well from delays and interruption in information flow, thus leading to a wasteful operation and inefficiencies in some processes. Thus, a new approach needs to be developed not only to ensure the control of information in a timely manner, but also to increase the level of communication between multiple processes/units for structural steel construction and to eliminate redundant activities. Wireless technologies can be used to improve the accuracy and timeliness of the data collected from sites. Wireless technologies have the potential to solve the communication problem, to increase collaboration, and to provide new capabilities through evolving technologies. Based on the information needed on the construction site, and the wastes identified in the different steel processes, a future research can be made to integrate different automated data acquisition technologies to collect data on construction sites, send the information through wireless connection to a central database to be stored, and then use these information to update the schedule and the project progress instantly as soon as the activities occur. It will allow the project engineer to track the quantity of materials and equipment usage on the construction site in a real-time fashion, and to be able to calculate the percentage of completed activities based on the tracking information. Once the updated model is developed, the different processes should be updated in the simulation model, thus the duration assigned for each activity will change accordingly, the time wasted occurred in the previous model would be eliminated, some activities will be deleted which make the cycle even faster, and most importantly will increase productivity when compared to the existing processes to quantify benefits.

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Appendix A

Simulation Output

STEEL ERECTION (Active Elements)						
Activity Type	No.	Name	Access Counts	Average Duration	Maximum Duration	Minimum Duration
COMBI	7	SPACING & RIGHT UP ELEMENT	303	3.0	6.2	0.0
COMBI	9	LIFT COLUMN	1202	1.0	3.3	0.0
COMBI	12	PLACE COLUMN	1202	0.5	1.9	0.0
COMBI	15	CON. COLUMN TO A.B.	1201	0.5	1.9	0.0
COMBI	19	CONNECT GIRDERS	604	1.5	4.7	0.0
COMBI	22	ERECT GIRDERS	604	2.0	5.2	0.0
COMBI	26	INSTALL BRACING	301	3.0	6.2	0.0
COMBI	29	INST. PURLINS AND GIRTS	300	3.0	6.2	0.0

STEEL ERECTION (Passive Elements)									
Type	No.	Name	Average Units Idle	Max. Idle Units	Times not empty	% Idle	Total Sim Time	Average Wt Time	Units at end
QUEUE	4	STEEL AVAIL	0.2	4	315.3	14.63	2155.9	1.1	1
QUEUE	5	CRANE IDLE	0.0	1	0.2	0.01	2155.9	0.0	0
QUEUE	6	WORKERS IDLE	1.0	2	2154.7	99.95	2155.9	1.4	1
GEN	8	COLUMNS AVAIL	15.1	27	2149.5	99.71	2155.9	26.9	13
QUEUE	10	A.B CAST	0.0	1	0.6	0.03	2155.9	0.0	0
QUEUE	11	WORKERS IDLE	3.0	4	2142.2	99.37	2155.9	2.4	2
QUEUE	13	WAIT TO FIX	0.0	2	8.7	0.41	2155.9	0.0	0
QUEUE	14	CONNECTOR IDLE	1.7	2	2092.6	97.06	2155.9	3.0	1
GEN	17	GIRDERS AVAIL	0.1	4	152.4	7.07	2155.9	0.3	0
QUEUE	18	CONNECTORS IDLE	1.0	2	1492.4	69.22	2155.9	1.8	2
QUEUE	20	CON.GIRD TO COL	0.7	8	779.0	36.13	2155.9	2.6	0
QUEUE	21	CRANE IDLE	0.4	1	938.6	43.54	2155.9	1.6	1
QUEUE	24	BRACING AVAIL	0.0	1	0.0	0.00	2155.9	0.0	0
QUEUE	25	WORKERS IDLE	1.6	2	2123.7	98.51	2155.9	11.2	1
QUEUE	27	PURLINS AND GIRTS AVAILABLE	0.1	2	122.8	5.70	2155.9	0.4	0
QUEUE	28	FORKLIFT IDLE	0.6	1	1260.4	58.46	2155.9	4.2	0