TIME STUDY ON TWO-ECHELON SUPPLY CHAIN FOR STEEL FRAMING CONSTRUCTION BY USING NETWORKING SIMULATION MODEL

Chun-Nen Huang[1], Yi, June Seong[2] and Jeffrey S. Russell[3]

ABSTRACT

This paper presents a case study to discuss the application of Supply Chain Management (SCM) concept to the structural steel construction industry. The impact of scheduling and resources distribution were identified and examined by using the following methodologies: 1. Time Study and 2. Networking Simulation Models.

Echelon I – steel-manufacturing phase: a simulation model has been developed based on the time study of steel beam fabrication in steel shop. This mock-up model can enables us to observe and study the different facets of its productivity, scheduled utilization, and production cost on different batch sizes.

Echelon II – construction job site phase: a CYCLONE simulation model has been developed based on two precedent studies: the time study of beams and columns erection under this model, which is simulated for the entire erection process, and the assessment of productivity and production cost over each task. This study has shown the fact that the project of using the design-build (D/B) delivery process has obtained higher productivity and lower production cost than that of using the design-bid-build (D/B/B) delivery process.

KEY WORDS

Supply chain, steel framing construction, time study, networking simulation.

1 Associate Research Fellow and Division Chief, Ph.D. of Univ. of Wisconsin at Madison, Division of Technology Application, Taiwan Construction Research Institute, 11F, No. 190, Sec.2, Chung-Hsing Rd., Hsintien, Taipei, Taiwan, R.O.C., Phone +866-2-98195099, FAX +866-2-86659747, chun-neh@tcri.org.tw

2 Assistant Professor, Department of Architecture, Ewha Womans Univ., 11-1 Dahyun-Dong, Seodaemun-gu, Seoul, 120-750, South Korea, Phone +82-2-32773517, jsyi@ewha.ac.kr

3 Professor, Department of Civil and Envir. Engrg., Univ. of Wisconsin at Madison, 2304 Engineering Hall, 1415 Engineering Drive, Madison, WI 53706 U.S.A., Phone +1 608/262-7244, FAX 608/265-9860, russell@engr.wisc.edu

INTRODUCTION

A supply chain is the sequence of process and flow that takes place among different stages (or echelons) as a combined product to meet customer's demand. From the manufacturing perspective, the term *supply chain* conjures images of products, services, projects, or supplies, moving from suppliers to manufacturers, distributors, retailers and finally to customers through specific chains (Chopra and Meindl 2001). The objective of supply chain is to optimize the overall value of the entire system.

Supply chain could be defined as simple as "a systematic wide-view of value creation." The issue of "uncertainty" has long been widely discussed and worked on, in terms of resolving the problem of supply chain in the community of lean construction (Howell and Ballard 1995; Alarcon 1997; Ballard and Howell 1998; Tommelein 1999; Mecca 2000). Comparing with those participating in the manufacturing scope, construction researchers have endeavored to develop supply chain ideas over a more dynamic construction environment (Koskela 1992; O'Brien 1998; Tommelein 1999). The philosophy of these ideas aimed at production theory, such as focusing on process improvement that is different from manufacturing perspective, focusing on multilevel inventory control. Subsequently, it is highly recommended that simulation technology, which is one of the operation-researching techniques that has been widely used in industrial systems and manufacturing fields, should be adopted, so as to confront uncertainty.

This paper has introduced precedent studies on the processes of both structural steel manufacturing phase and construction installation phase by Marshall Erdman and Associates (ME&A) on Madison, Wisconsin, USA. In the steel fabrication phase, an ARENA software simulation model for beam assembly line was developed in this paper. In the construction job site phase, a CYCLONE simulation model was developed based on time study of beams and columns erection from two case studies. The two case studies showed different performances using different delivery: design-build (D/B) method and design-bid-build (D/B/B) method.

RESEARCH METHODOLOGY

Organizing the topic of SCM in steel framing construction is complicate and a great number of processes are dynamic. Systematic approach is an appropriate method to explore such subject. Modeling techniques for systems analysis are quantitative, including analytical, simulation and statistical models. This paper proposes a systematic approach to explore research methodologies and uses statistical models to analyze the process.

ECHELON I – STEEL MANUFACTURING PHASE

THE PROCESS FLOW

The process of structural steel parts production, which is an extremely complicated endeavor, has to undergo two assembly lines (one for column product and the other for beam one) and four working booths (painting, stairs, accessory parts and handrails booths) consisting of 1 manager and 14 crewmembers in the shop. Each assembly line includes three stations with 3 participants (including a foreman). If it is under tight job site schedule, 4 workers should be employed instead of 3. The process flow diagram shown in Figure 1 is a fairly general situation that is similar to any steel assembly lines in the other steel shop. Several points about the diagram should be noted:

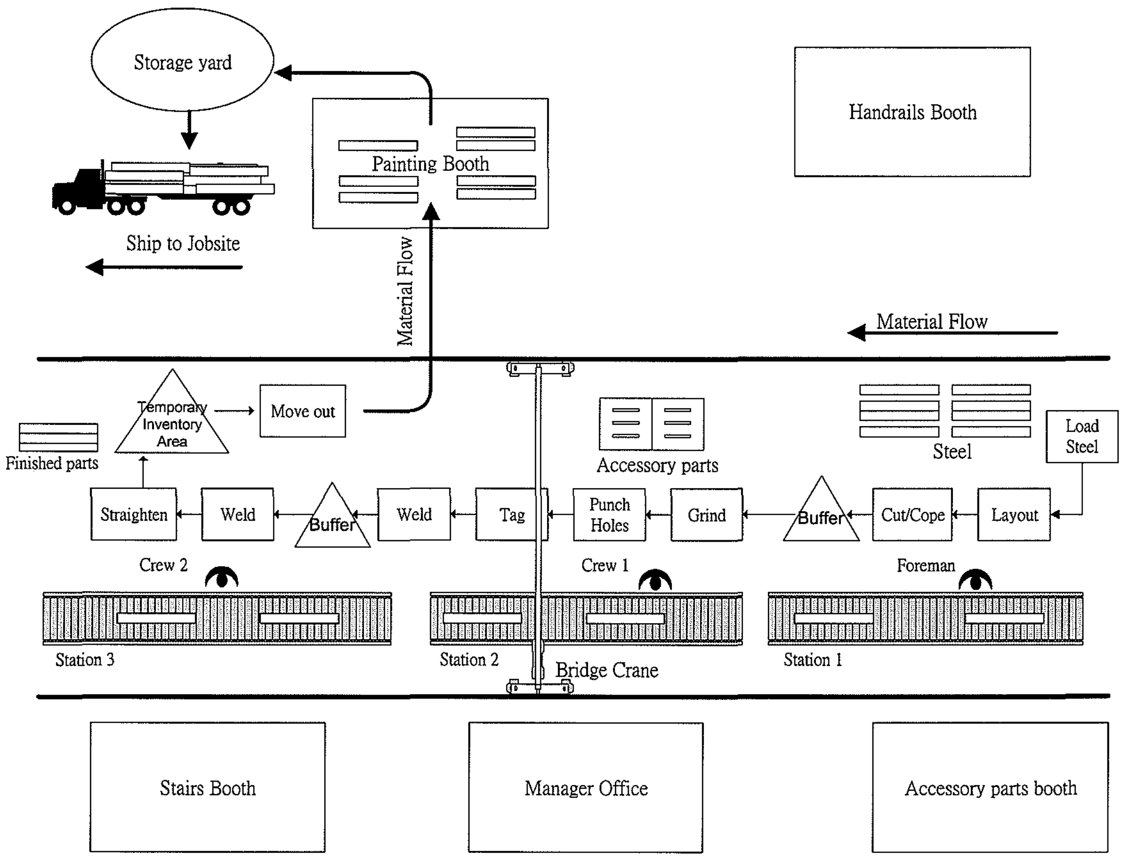

Figure 1. Process Flow Diagram and Layout of Steel Shop (ME&A)

- Actual processing operation is usually distinguished from storage points in the process. In the diagram, processing operations are indicated by rectangles and inventories by triangles.
- Naturally, in a "*job shop*" environment like ME&A' steel shop with many low production-quantity, one-of-a-kind tasks, the foreman is responsible for coordinating a flexible and smooth process of production line.
- On average, this process takes 20 minutes to produce a beam. However, the performance is highly depended on the beam's configuration. The more complicate the structure of beam, the more production time is required. The welding process takes more time and is often the jam process of the production line. According to the analysis of historical data, the productivity of welding time is only 5% on production line, which is relatively low on

productivity when comparing with that of other industries (25-50%) and robots manufacturing process (50-90%).

- Sometimes, the production line would be jammed if the crew at station 3 is busy. Under this situation, the crew at station 2 need to help station 3 in order to release the working space of stacking the materials that are shifted from the station 1 (foreman).

THE CURRENT PROBLEMS ON SCHEDULING PLANNING

ME&A Company takes the advantages of "Design-Build" delivery system; the philosophy of the entire manufacturing system is based upon the "fast-track" concept, so that the overall production system can save time and cost. Due to overlapping in the processes by using fast-track concept, production scheduling is hard to predict and control. ME&A uses building's "square foot" to be the measurement unit in its prediction method. This measurement unit works well for a long-term prediction (e.g. annually or half of year); however, it creates many problems for short-term schedule planning (e.g. monthly or weekly) due to its inaccuracy. These problems could result in underestimating or overestimating the production capacity and the labor assembly hours etc., which ultimately causes delay in job site demand. The previous research has developed numerous models for a more accurate prediction of steel assembly hours by using multi-variables linear regression methods (Huang 2003).

SIMULATION MODEL AND TIME STUDY

In this section, we have developed a simulation model for beam assembly line of steel fabrication by Arena simulation software (Kelton and Sadowski, 2002). Figure 2 illustrates the workflow for steel units that undergo the beam production line in ME&A steel shop. Three stations, consisting of 12 activities (shaded) in the beam fabrication system, are the main processes in this study of structural steel fabrication. In order to acquire the theoretical distribution, time study for each activity has been conducted. Even though there are three stations in the process, basically this assembly process can be modeled as *M/M/1*[3] system, which utilizes exponential distribution (used for most cases) to analyze the service types and arrival times. Every repetitive activity or work task has its own delay time and probability distribution. According to the existing industrial experiences, the service time (processing time) in a single-server queuing model *M/M/1* can be treated as exponential distribution in a job shop environment (Law and Kelton, 2000). Table 1 summarized the results of beam fabrication service times over activity. Also, we have applied the "Input Analyzer" tool of Arena simulation software (Academic version 5.00.02) to analyze the resulted data.

[3] The first "M" states that the arrival time distribution and second "M" stands for the service-time distribution, it is treated as exponential for most of cases in manufacturing system. The "1" indicates that there just a single server. Here, it represents a single beam production line with 3 stations.

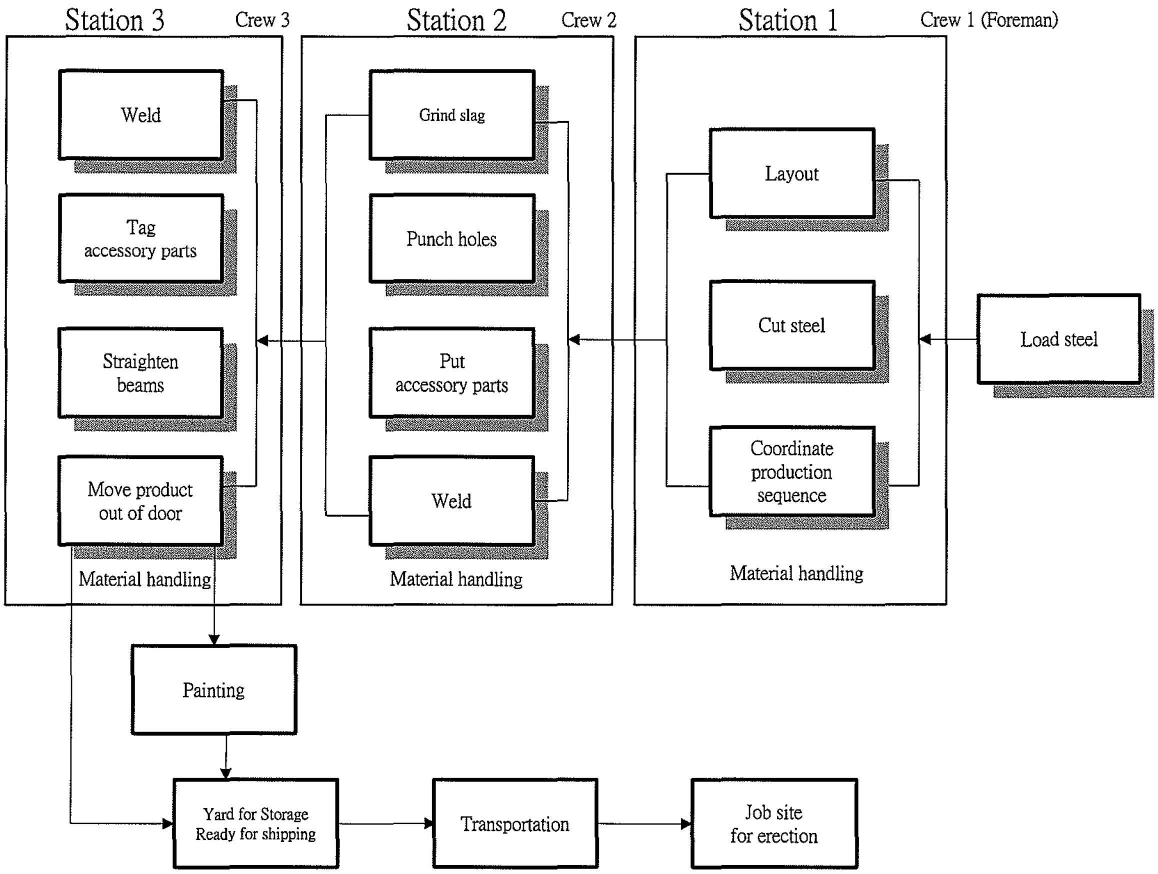

Figure 2. Workflow for Steel Fabrication

Figure 3 illustrates the simulation model that has developed on beam fabrication assembly line of this study. The model was established by 16 activities that were based upon the logic flow of beam fabrication in ME&A's steel shop.

SIMULATION RESULTS

Based on the simulation model interpreted in the previous section, the outcome of simulation results is described below.

Productivity vs. Batch Size

Figure 4 illustrates the relationship productivity versus different batch sizes. It indicates that the maximum productivity happens at 3.53 units per hour while the batch size is at 40 (or 40 to 50).

Figure 3. Arena Model for Steel Fabrication Simulation

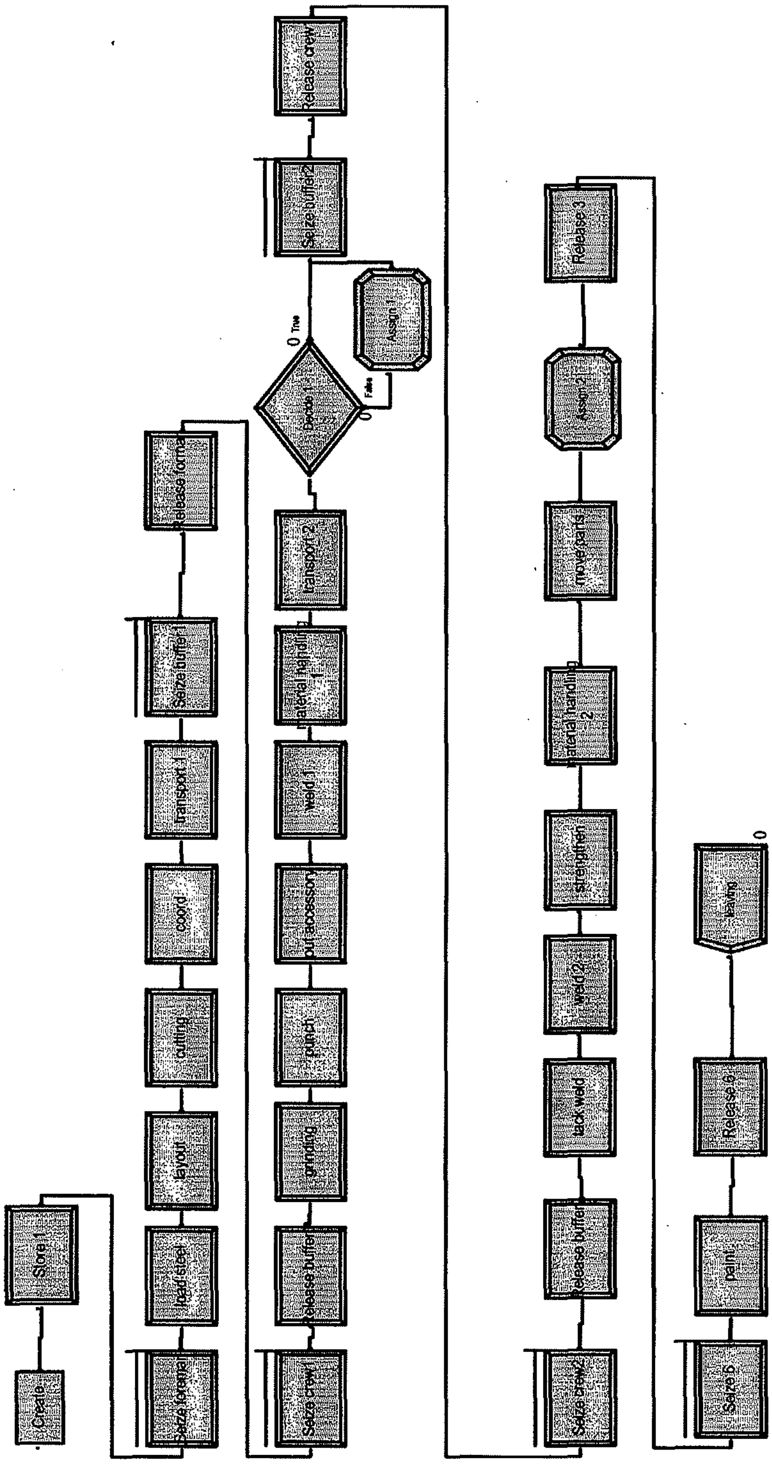

Table 1. Activity Duration of Beam Fabrication (ME&A)

Station	Activity	Duration (Minutes)			Type of distribution	Expression
		Mean (μ)	S.D. (σ)	CV* (σ / μ)		
1	Load steel	1.55	0.403	26.01%	Exponential	EXPO(1.55)
	Layout	6.27	1.524	24.31%	Exponential	EXPO(6.27)
	Cut/Cope	4.36	3.115	71.52%	Exponential	1+EXPO(4.38)
	Coordinate	1.03	1.470	143.43%	Exponential	EXPO(1.67)
2	Grind slag	1.62	0.818	50.48%	Normal	NORM(1.62, 0.803)
	Punch holes	1.65	4.162	252.99%	Beta	1+13*BETA(0.498, 1.25)
	Put Accessory	0.21	0.099	48.46%	Deterministic	0.21
	Weld (S2)	3.41	1.238	36.30%	Triangular	TRIA(2, 3.74, 6.78)
3	Weld (S3)	2.20	1.904	86.76%	Erlang	ERLA(0.955, 3)
	Tack weld	1.29	0.614	47.52%	Lognormal	0.33+LOGN(0.949, 0.525)
	Straighten	3.64	2.205	60.54%	Exponential	EXPO(3.64)
	Move out	5.36	2.065	38.52%	Exponential	EXPO(5.36/8)*
Others	Material handling	0.88	0.695	78.69%	Lognormal	LOGN(0.9, 0.855)
	Material transport	1.24	0.562	45.25%	Exponential	0.41+EXPO(0.703)

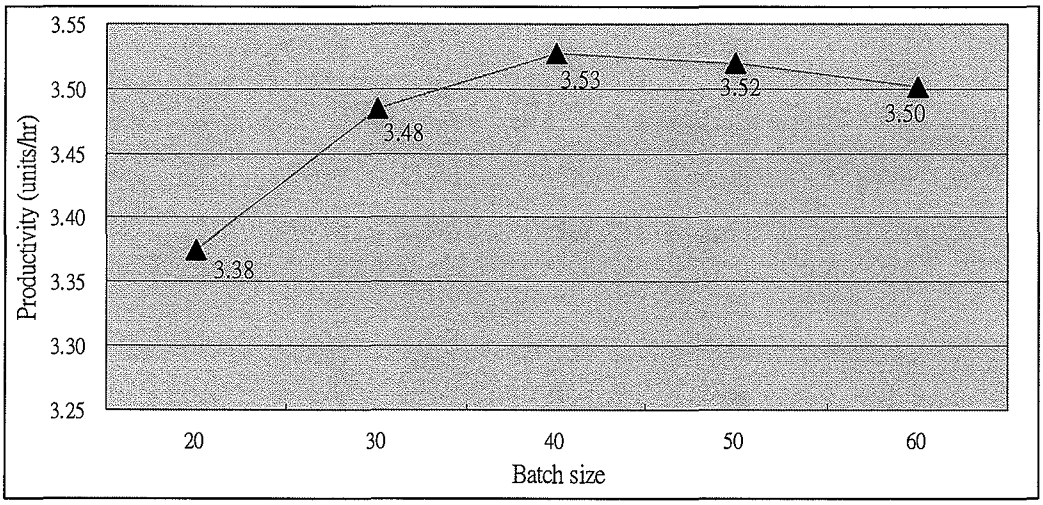

Figure 4. Productivity vs. Different Batch Size (beam production line)

Scheduled Utilization

For each resource, Arena reports two utilization statistics, called "Utilization" and "Scheduled Utilization". They are defined and described as below (Kelton, 2002):

$$\text{Utilization} = \frac{\int_0^T U(t)dt}{T} = \frac{1}{T}\int_0^T \frac{B(t)}{M(t)}dt,$$

where, T is the length of the simulation,

$B(t)$ is the number of units of a particular Resource that are busy at time t,

$M(t)$ is the number of units of that Resource that are available (busy or not) at time t,

$0 \le B(t) \le M(t)$ at all times t,

If the Resource has a fixed capacity, then $M(t)$ is a fixed constant for all t, but if the Resource capacity follows a variable schedule, then $M(t)$ will vary with t. In other words, Utilization is the (time) average of the ratio of the number busy to the number available, which measures how well the staffing plan tracks demand over time. Besides, Arena also reports the Scheduled Utilization, which is the ratio of the average number busy to the average number available:

$$\text{Scheduled Utilization} = \frac{\int_0^T B(t)dt \Big/ T}{\int_0^T M(t)dt \Big/ T} = \frac{\int_0^T B(t)dt}{\int_0^T M(t)dt}$$

If the Resource has a fixed Capacity, then it is easy to show that Utilization and Scheduled Utilization will be the same. However, these two statistics are the same in this study. Table 2 shows the simulation results (10 runs) for Scheduled Utilization on foreman (station 1), crew 1 (station 2) and crew 2 (station 3). Foreman has the highest scheduled utilization of 93.37% on average. Crew 2 has the lowest scheduled utilization of 65.10% on average.

Table 2. Scheduled Utilization of Resources in Different Batch Sizes (ME&A)

Batch size / Resources	Scheduled Utilization (%)					Average
	20	30	40	50	60	
Foreman (Station 1)	89.93%	92.15%	94.45%	95.19%	95.12%	**93.37%**
Crew 1 (Station 2)	83.28%	84.58%	84.07%	84.52%	86.16%	**84.52%**
Crew 2 (Station 3)	61.82%	63.51%	64.02%	63.75%	72.40%	**65.10%**

Costing

In the resources, it cost US $22/hour for a foreman and US $18 for a crew 1 and crew 2. In order to obtain meaningful cost statistics, costing data had been entered into the model in advance. After running the simulation, costing information had been automatically accumulated by Arena simulation software. These costs include busy cost, idle cost for each resource respectively and total busy cost, total idle cost and total wait-time cost for the system. Table 3 shows the result (10 runs) of the cost statistics on each resource and entire system in different batch size.

Table 3. Cost Statistics in Different Batch Sizes (ME&A)

Resources	Batch size	Cost Statistics (dollars)				
		20	30	40	50	60
Foreman	Busy Cost	128.65	190.84	257.71	325.49	392.76
	Idle Cost	14.17	16.27	15.18	16.46	19.87
Crew 1	Busy Cost	79.06	116.71	152.86	192.57	236.25
	Idle Cost	16.16	21.36	29.61	35.40	38.84
Crew 2	Busy Cost	58.79	87.55	116.15	144.93	198.72
	Idle Cost	36.43	50.53	65.78	83.03	76.36
Total Wait Cost		0.99	1.48	1.93	3.617	16.08
Total Busy Cost		266.50	395.10	526.74	663.00	827.74
Total Idle Cost		66.76	88.17	110.03	134.89	135.07

ECHELON II – CONSTRUCTION JOB SITE

CONSTRUCTION JOB-SITE ON TWO CASE STUDIES

The data of this research were collected as part of two ongoing projects in downtown Madison of Wisconsin. Table 4 provides the summary of statistical result indicating the similarity and difference between the two projects.

Table 4. Summary of Project Statistics

Item	Project Features	Project A	Project B
1	Location	UW-Madison campus, downtown Madison, WI	East downtown, Madison, WI
2	Contract type	Design/Bid/Build	Design/Build
3	Ownership	Public sector (State Government)	Private sector (Dean Health)
4	Type of structural frame	Wide flange	Bar joints
5	Number of stories	5	5
6	Building heights (ft)	102	138.5
7	Contract amount	$ 25,222,000	$ 21,091,042
8	Structural Steel Sub-amount	$ 4,715,000	$ 2,116,692
9	Ratio of metal over project (= Item 5 / Item 4)	18.69 %	10.03 %
10	Project area (sq ft)	255,000 (for all quads)	145,572

		146,472 (A, B quads)	
11	First floor plan area (sq ft)	160,600 (for all quads) 38,618 (A, B quads)	37,530
12	Site area (sq ft)	40,643	48,530
13	Building-to-site area ratio	0.95	0.77
14	Number of pieces	1,417 (A, B quads)	1,788
16	Cost structure for labor	Foreman = $ 60 / hr Ironworker = $ 52.07 /hr	Foreman = $ 60 / hr Ironworker = $ 40 /hr
17	Crane Capacity (tons)	230	65
18	Crane rental fee	$ 1,200 / per day	$ 1,000/ per day
19	Crane source	Owned by General contractor	Rented by Subcontractor

CYCLONE Models for Steel Erection Operations

Operations relating to steel building erection are excellent candidates for production simulation modeling since they are highly linear and repetitive. This process involves coordination between several cycles. The major cycles are (1) the steel off-load cycle (2) the column erection cycle (3) the beam erection cycle (4) the deck erection cycle. The following resources and cycles could be studied when modeling a steel erection operation: (1) crane (2) forklift (3) groundman (the person checking for correct steel parts) (4) ironworkers (2 people in a crew) (5) Space (steel storage yard in job site)

Time Study on Duration

Fitting theoretical distributions to data source is popular. Each of repetitive processes and work tasks has a unique performance duration that could be constant (deterministic) or distributed (stochastic). Standard techniques of statistical inference are used to "fit" a theoretical distribution form, e.g., beta or exponential, to the data source and perform hypothesis tests to determine the suitability of fit. Due to the limitation of the length herein this paper, the process of time study and distribution analysis cannot be elaborated in this paper. Please refer to Huang's work if readers are interested in this specific area (Huang, 2003).

SIMULATION RESULTS

Productivity Perspectives

The following Figures 5 and 6 show the comparison between productivity output and cost consumption based on the simulation result. In productivity perspective, project B (Deign-Build delivery) has higher productivity output on beam and deck erection (11.65 and 11.99 units per hour respectively) than project A (9.58 and 7.92 units per hour). However, project B has lower productivity output on column erection (4.59 units per hour) than project A (6.31 units per hour).

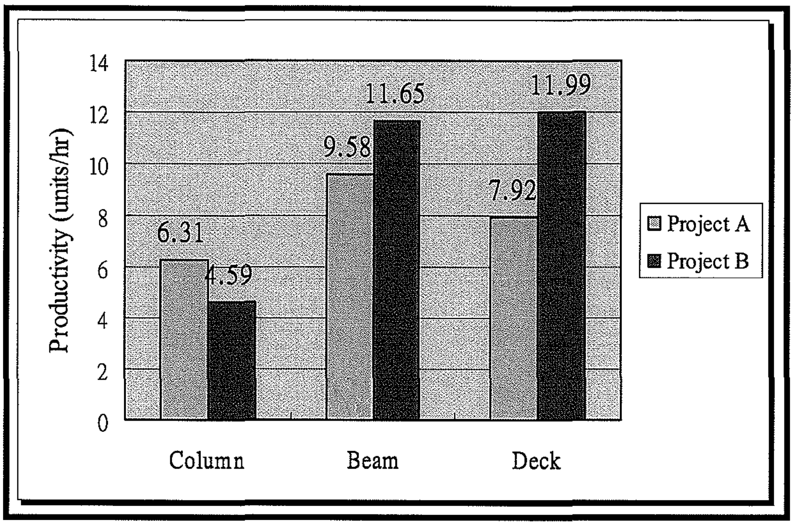

Figure 5. Productivity Output Comparison Between Two Case Studies

Cost Perspectives

In cost perspective, project A has higher cost consumption on beam and deck erection ($33.68 and $40.73 U.S. dollars per unit respectively) than project B ($27.79 and $27.01 U.S. dollars per unit). But project B has higher cost consumption on column ($63.91 U.S. dollars per unit) than project A ($47.71 U.S. dollars per unit).

System Perspectives on Erection Activity

The structural steel has different portion of pieces in member combinations. As an example, numbers of beams (including girders, w-shape beams, bar-joints) consist of 1,661 pieces in project B. Beam erection constitutes over 90 percent of erection activities. On the other hand, column erection only involves 127 pieces, which is less than 10 percent of the total erection activities. Therefore, the lowered cost for beam erection is extremely cost effective and can benefit the overall erection operation cost.

CONCLUSIONS

In conclusion, this research study has offered multiple facets of statistical and simulation models based on the time study of two-echelon supply chain for steel framing construction, which are further used to determine the degree of "uncertainty" in construction process. In general, this research can be used as a decision-making tool to control any unpredictable environments in construction industry.

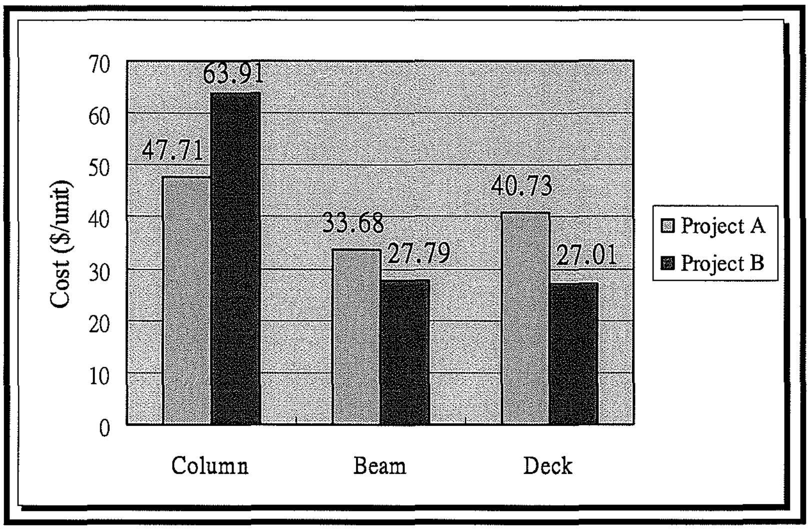

Figure 6. Cost Consumption Comparisons on Two Case Studies

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