ASSESSING THE ENVIRONMENTAL IMPACTS OF LEAN SUPPLY SYSTEM: A CASE STUDY OF HIGH-RISE CONDOMINIUM CONSTRUCTION IN SEOUL, KOREA

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ABSTRACT

Prefabrication and just-in-time delivery are important in lean supply system. Past research focuses on how much lead time is reduced and how much costs are saved, but few have studied on the environmental impacts.

While most studies on the environmental impacts have focused on select life-cycle phases or specific building materials and components, the impacts of different construction methods or supply strategies from the construction phase are ignored or simply approximated. This paper presents results of a case study where the environmental impacts of prefabrication and just-in-time delivery strategy of rebar supply on a high-rise condominium project in Seal, Korea.

KEY WORDS

rebar supply system, prefabrication, just-in-time delivery, case study, environmental impacts

INTRODUCTION

In 1992, a UN conference on Environmental Development reintroduced the concept of "sustainability" and defined it as: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The term, "triple bottom line" evolved as a basis for sustainable development: economic, environmental, and social areas (Elkington, 1997). The construction industry is one of the largest and most important industries, yet at the same time is one of the largest polluters (Horvath, 2004). The construction industry has potential to advance sustainability practices.

Attempts to assess sustainable impacts have already been made to evaluate the life-cycle effects of commercial buildings (Junnila and Horvath 2003), but most studies thus far have focused on specific building materials (Guggemos and Horvath 2005). In many studies, the impacts from the construction material supply system are ignored or simply approximated because the analysis of supply system is complicated or the methodologies of analysis are limited. While most relevant research regarding supply system focused on how lead time can be reduced using either process improvements or external integration with suppliers

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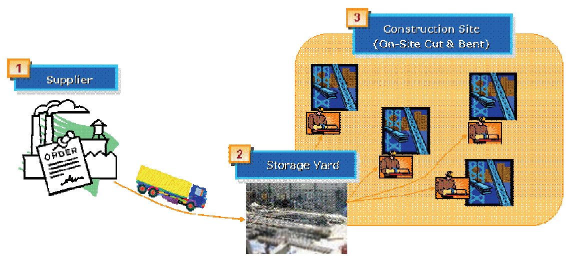
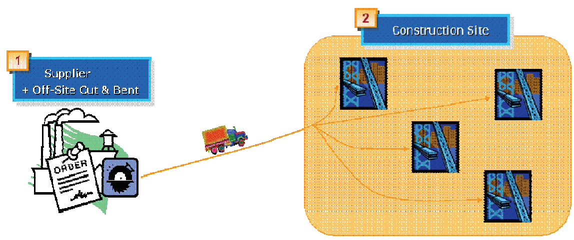
(Kim et al. 1997; Arbulu et al. 2003; Akel et al. 2004), few research studies have investigated the environmental impacts of a new material supply system even though it is critical in terms of sustainability (Bae and Kim 2007).

The supply system of reinforced steel bar to construction is considered one of critical factors in meeting budget and schedule goals of a construction project (Polat and Ballard 2003).The tradition of the construction industry has long been to fabricate (i.e., cut and bend) rebar on-site and rebar is delivered to the site on large batches. The traditional rebar supply system requires large on-site yard and holding costs. Since people recognized the holding costs including yard space requirements, a new method has gained industry attention especially in construction projects in metropolitan areas. A new rebar supply system uses off-site cut& bent (i.e., prefabrication) with a frequent delivery of small batch (Figure 1). Even though this new system requires more frequent deliveries, it removes yard space requirements and deliveries within the sites (i.e, on-site yard to building). A recent study showed that a lean rebar supply system reduces the need for inventory space on sites and improves productivity due to prefabrication (Arbulu and Ballard 2004).



(a) Traditional Supply Chain



(b) JIT Supply Chain

Figure 1: Rebar Traditional and JIT Supply Chain Diagram

RESEARCH GOALS AND PROCEDURE

The authors studied two apartment construction projects. The projects were similar in all aspects except for their rebar supply chains: one is using onsite fabrication and one using prefabrication-JIT delivery system. The authors investigated the environmental impacts of these supply systems: emission characteristics, energy consumption, and material loss rate depending on the type of supply chain. The assumption is that only one kind of heavy-duty truck was used because in both cases, the projects were large enough to have batch sizes larger than 20 tons of rebar. Considering just one option of transport greatly simplifies the analysis. Because the construction phases of the two projects were different, the data was gathered for two months during which rebar works were conducted most actively. These two months are represented by month A and B.

In this paper, the authors studied fabrication, delivery, and minor movements in construction sites of rebar products. The authors made several assumptions and estimations due to the lack of data and the differences between the supply chains.

CASE STUDY

The general contractor (GS E&C) recognized the huge amount of material waste on construction sites. In order to improve inventory management, the company considered the development of an advanced inventory management system, which could reduce inventory waste. This led to the introduction of the Just-In-Time (JIT) process as a potential solution for their inventory management.

PUSAN HIGHTS XI AND SEOUL BANPO XI APARTMENTS PROJECTS (BATCH VS. JIT SUPPLY CHAIN)

The construction of the Pusan Heights Apartments Project was conducted from June 2005 to October 2007. The project consisted of two 39-story buildings and three 30-story buildings. The raw rebar was delivered directly from a raw rebar supplier using a batch supply chain, and processed on the construction site.

The general contractor established a rebar processing plant near Seoul, Korea in 2005 and supplied rebar to a Banpo apartment construction site. The rebar was distributed using the JIT. The goal of the rebar processing plant is to minimize the amount of loss due to rebar waste, meet the exact specifications of the reinforcing process, and eliminate the space for inventory loading and field works. The construction sites, rebar processing plants, and an estimating firm cooperate through the rebar processing plant operating system.

The rebar consumptions in the Pusan Heights *Xi* project and Seoul Banpo *Xi* project are shown in the Table 1. Due to the differences between these projects in fabrication and supply chain systems, some data, such as electricity-related data, are not given in same manner. Therefore, the authors estimated several items using the aggregated data.

Table 1. Rebar Consumption in the Two Apartment Projects in Month A and B

Project	Pusan Heights Xi (Batch Supply Chain)		Seoul Banpo Xi (JIT Supply Chain)	
Month	A	B	A	B
Total Rebar Consumption (ton)	2,025	1,800	4,900	5,200
Total Rebar Production of the Prefab. Plant (ton)	-	-	12,900	12,000

ENERGY CONSUMPTION DURING REBAR MANUFACTURING

Equipment types and the monthly duration of use for rebar processing are shown in Table 2. Monthly hours of use per unit, the number of units, and operation rates for rebar movement were given from the survey questionnaire completed by project managers of two designated projects. Based on the data, hours of use for each equipment were estimated for several projects proportionally. For instance, a crane at the rebar prefabrication plant works for several projects including the Banpo *Xi* project. In this case, the authors calculated the contribution of the crane based on the hours of use of the total operation time.

Table 2. Equipment Types and Monthly Duration of Use for Rebar Processing

Location	Equipment	Use (h)		Power Source	Power [diesel (hp)] [electric (W)]
		Heights Xi (Batch)	Banpo Xi (JIT)		
Prefabrication Plant	Crane	-	125[1]	Diesel	450
	Rebar Bender/Cutter	-	374[2]	Electric	1,200
	Forklift	-	300[3]	Diesel	125
Site	Tower Crane	35[4]	60[5]	Diesel	450
	Rebar Bender/Cutter	160[6]	-	Electric	850
	Forklift	228[7]	96[8]	Diesel	125

1. *290 hours (hours of use per unit) x 1 unit x 43%. The authors use a 43 percent (4,900 tons of total rebar consumption / 12,900 tons of total monthly production of a rebar manufacturing plant) to calculate the hours of use for Banpo Xi project.*
2. *290 hours (hours of use per unit) x 4 units x 43%.*
3. *174 hours (hours of use per unit) x 4 units x 43%*
4. *10 hours (hours of use per unit) x 5 units x 70% (operation rate for rebar movement)*
5. *10 hours (hours of use per unit) x 10 units x 60% (operation rate for rebar movement)*
6. *160 hours (hours of use per unit) x 1 units*
7. *112 hours (hours of use per unit) x 2 units*
8. *48 hours (hours of use per unit) x 2 units*

The authors estimated the electricity consumption for the Banpo Xi project from two work stations, which are a rebar prefabrication plant and a construction site. The electricity consumption for Banpo Xi project was estimated from the portion of rebar consumption to the total rebar production of the plant proportionally. The plant produced 12,900 tons of rebar products in month A. From this amount, 4,900 tons of rebar products were delivered to Banpo Xi project. Therefore, it can be assumed that 43 percent of total energy consumption in the plant was assigned for the Banpo Xi project.

Table 3 shows the energy consumption figures for the two projects. Heights Xi and Banpo Xi project consumed 136,000 Wh and 448,800 Wh of electric power and 44,250 hph and 132,750 hph of diesel power respectively. Energy consumption per rebar product for the projects could be estimated based on these data. According to the analysis, the project using JIT supply system consumed more electricity because the fabrication shop uses high capacity equipment.

Table 3. Energy Consumption for Rebar Production for Heights Xi and Banpo Xi Projects

Project	Pusan Heights Xi (Traditional Supply Chain)		Seoul Banpo Xi (JIT Supply Chain)	
Month	A	B	A	B
Total Electric Power (Wh)	136,000		448,800	
Electric Power per Rebar Production (Wh/ton)	67	76	92	86
Total Diesel Power (hph)	44,250		132,750	
Diesel Power per Rebar Production (hph/ton)	22	25	27	26

ENERGY CONSUMPTION AND CO_2 EMISSION DURING TRANSPORTATION

The amount of carbon in the fuel is one of the major factors of carbon dioxide (CO2) emissions from a truck. Although carbon content in diesel fuel varies, the Code of Federal Regulations (40 CFR 600.113) suggests the average value for carbon content per gallon of diesel fuel as 2,778 grams. The Intergovernmental Panel on Climate Change (IPCC) requires that the 0.99 of oxidation factor should be considered for all oil and oil products, because a small portion of the fuel is not oxidized into CO2. In order to calculate the CO2 emissions from diesel fuel, the last factor needed to be considered is the ratio of the molecular weight of CO2 (m.w.44), to the molecular weight of carbon (m.w.12): 44/12.

With this value, U.S. Environmental Protection Agency (2005) calculated CO2 emissions from a gallon of diesel:

CO2 emissions from a gallon of diesel = 2,778 grams x 0.99 x (44/12)/gallon = 10,084 grams/gallon = 22.2 pounds/gallon··①

The U.S. Department of Commerce, Bureau of the Census (2002) classified a truck by weight in the 2002 Vehicle Inventory and Use Survey (VIUS), which is data on the physical and operational characteristics of the Nation's truck population. According to the VIUS, a truck that weighs 33,001 lbs and up has a 5.7 mile per gallon of harmonic mean fuel economy, which may be converted to 0.17 gallons per mile. Therefore,

Total diesel consumption (gallon) = Total delivery distance (mile) x 0.17 gallon/mile·②

Finally from the formula ①, ②,

Total CO emission = Total diesel consumption x 22.2 pounds/gallon·③

In table 4, data including total rebar consumption, delivery amounts per truck, number of deliveries, and delivery distances for the Heights *Xi* and Banpo *Xi* projects was estimated and the total diesel consumption and total CO2 emission were calculated based on the formula ①, ②, and ③.

Table 4. Fuel Consumption, and CO2 Emission

Project	Heights Xi (Traditional Supply Chain)		Banpo Xi (JIT Supply Chain)	
Month	A	B	A	B
Total Rebar Consumption (ton)	2,025	1,800	4,900	5,200
Delivery Amount per Truck (ton)	25	25	21	20
# of Delivery	81	72	223	259
Round Trip Delivery Distance (mile)[1]	60			
Total Delivery Distance (mile)	4,860	4,320	13,380	15,540
Total Diesel Consumption (gallon)	826	734	2,275	2,642
Diesel Consumption per Rebar Consumption (gallon/ton)	0.408	0.408	0.464	0.508
Total CO2 Emission (pound)	18,337	16,295	50,505	58,652
CO2 Emission per Rebar Consumption (pound / ton)	9	9	10.3	11.3

1. The authors assume that the one-way delivery distances both from a raw rebar supplier and a rebar prefabrication plant to a construction job site are same, which is 30 miles.

Delivery distance is one of the critical factors that affect CO2 emission per rebar consumption. If the delivery distances are changed, the difference between the CO2 emission per rebar consumption of batch and JIT supply chain is also changed. For example, in the case that the delivery distances are assumed as 40 and 80 miles, the differences between CO2 emission per rebar consumption of batch and JIT are changed to 1.16 and 2.31 pound/ton accordingly. When the delivery distance is changed by 20 miles, CO2 emission per rebar consumption is also changed by 0.578 pound/ton contrarily. Therefore, the JIT supply system produces less CO2 emission in the cases where the delivery distance is shortened.

REBAR LOSS

The general contractor estimated a rebar loss rate of 3 percent for the Heights Xi construction project, and a 1.4 percent loss rate for the Banpo Xi project. The well-planned rebar product processing in a rebar fabrication plant may reduce the on-site rebar loss rate caused by disorganized cuttings, and the stockpiling of rebar on construction sites which often results in rust and theft of rebar.

Table 5. Rebar Loss Amounts in JIT and Batch Supply Chains

Project	Heights Xi (Traditional Supply Chain)		Banpo Xi (JIT Supply Chain)	
Month	A	B	A	B
Total Rebar Consumption (ton)	2,025	1,800	4,900	5,200
Rebar Loss Rate (%)	3		1.4	
Total Rebar Loss (ton)	61	54	69	73

If total rebar consumption in the two projects were the same (3,000 ton), the amount of rebar loss for the two projects would be 90 tons and 42 tons respectively.

CONCLUSION

The environmental impact of delivery and fabrication type of construction materials is a significant issue. In this paper, CO2 emission, energy consumption, and material loss amounts for two types of rebar supply systems are compared. In our analysis, considering fuel consumption and CO2 emission, JIT is not environmental friendly. The main impediment is delivery distance. According to our analysis, JIT increases energy and CO2 emission per rebar consumption during rebar fabrication and transportation, especially when delivery distances are increased. If JIT is used in a case where delivery distance is short, it can be an environmentally-friendly option with decreased inventory loss rate.

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