Optimising Time and Cost in Construction Material Logistics

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Abstract:
Materials are important in every construction project as they contribute to a significant proportion of the total construction costs. As a result, planners and managers would strive to plan and control the ordering, distribution and storage of materials (i.e. the logistics process) carefully in order to maximize the productivity. Despite that, there is a lack of simple but powerful formalism to analyze and model the logistics process under a dynamic environment. This research aims to resolve the problem and facilitate the decision-makers to increase the productivity while minimizing the cost through better logistics arrangement. In this research, the common material logistics practices are revealed and a material management tool by referring to the acquisition cost is devised. Time and cost are both considered by linking the schedule of material delivery to the construction program to establish the determinant variables which could affect the material acquisition costs. Genetic algorithms are used to generate the best working and delivery schedules with the lowest material acquisition cost. The results of this research can be used for re-engineering and improving the logistics management at the stage of planning changes and evaluating the effects of those changes before such a decision is made.

Keywords:
Acquisition cost, buffer stock, construction material, genetic algorithms, materials logistics.

1. Practice in Construction Industry

The construction industry is highly fragmented which could lead to significant negative impacts, not least low productivity, cost and time overrun, conflicts and disputes resulting in claims and time consuming litigation (Tucker *et al*, 2001). An investigation into the time consumption reveals that the site workforce spends considerable amount of time waiting for the ordering and delivery of materials. The non-value-adding activities were found to be as high as 40 percent of the overall project duration from the inception to completion stages (Mohamed, 1996).

Evbuomwan and Anumba (1998) summarized that the problems of construction industry lied with its (i) difficulty in capturing, structuring, prioritizing and implementing client's needs; (ii) dispersed design, fabrication and construction data making it difficult to convey the data to the downstream; (iii) reliance on pseudo-optimal design solutions; (iv) lack of integration, co-ordination and collaboration between various disciplines during the life-cycle of a project; and (v) poor communication of design intention and rationale resulting in unwarranted design changes, inadequate design specifications, unnecessary liability claims, and increase in project time and cost.

Construction Industry Institute of United States concluded in their industry-wide investigation that project performance measured in terms of cost, schedule, technical, quality, safety and profit objectives had rooms for substantial improvement as a whole (Anderson, 1990). Construction Industry Board, United Kingdom suggested that the construction industry should be more competitive and shall aim at reducing the construction costs by 30 percent (Garnett, 2000). Mohamed (1996) reckoned that 25 percent of time saving can be achieved in a typical construction work package without any increase in the allocated resources (Yeo, 2002). Logistics management is, therefore, an important way to realize the objective of improving construction productivity.

2. Construction Material Logistics

Construction logistics comprises planning, organization, coordination, and control of the materials flow from the extraction of raw materials to the incorporation into the finished building (Clausen, 1995). Construction logistic management is the management of material and information flow throughout the project life cycle. Transport and distribution are the cornerstones of logistics and it is the most visible manifestations (Canadine, 1996). Previous studies pointed out that the cost of materials in a typical construction project can be as much as 70 percent of the total construction costs (Sobotka and Czarnigowska, 2005). Materials control 80 percent of the project schedule from acquisition to use (Stewart, 2004). Apart from the direct cost, the costs of materials also embrace the logistic cost. In the absence of much room to significantly reduce the direct cost, managers would try to minimize the costs pertinent to material logistics including transportation and storage.

The importance of logistic cost was highlighted in many studies. For instance, an empirical study in Finland (Wegelius, 2001) found that the total logistic costs for the supply of plasterboard accounted for 27 percent of its purchase price. Sobotka and Czarnigowska (2005) postulated that any actions towards the rationalization of size, structure and organisation of material consumption, along with proper planning of delivery and storage can increase project efficiency. As global sourcing is becoming a trend in today’s competitive market, capturing and evaluating the logistics costs involved in a global supply chain appears to be an increasingly critical strategic benefit (Fagan, 1991).

3. Research method

Numerous factors can drive up logistics costs substantially, which may offset the benefits of having business with international suppliers. One way to account for the logistics cost was presented by van Damme and van der Zon (1999). They employed an Activity-Based Costing (ABC) approach to analyze the financial information so as to help top management making logistics decision. Maltz and Ellram (1997) identified those logistics activities that could affect the outsourcing decisions and they presented a ten-step procedure to compare the make or buy alternatives using the total cost relationships. Some researchers, on the other hand, focused on domestic logistics systems where the optimal order / purchase quantity was derived based on minimizing the system cost for a particular transportation mode (Lee, 1986; Russell and Krajewski, 1991; Tersine and Barman, 1991; Bertazzi *et al*, 1995; Tyworth and Zeng, 1998).

Despite many research about logistics cost can be found in the manufacturing industry, similar studies in the construction discipline are not as popular. Yet, cost management in construction is not a new topic and has been developed for many years. But when considering construction logistics in terms of costs, it is a new area with little attention. Research in construction supply chain does show there is certain relationship with the costs. There is a need to identify ways to lower the cost and time consumed apart from uplifting project quality.

The purpose of this paper is to assist management to analyze construction logistics by relating to the costs of those activities and their influences. The paper focuses on the use of the ABC approach in allocating the cost of activities to the specific cost objects involved when implementing the ABC concept within the construction logistics process.

ABC is a method by which critical cost data is gathered for analysis and utilized either in a single work process or among the entire project. It is defined as a system of "calculating the costs of individual activities and assigning those costs to cost objects such as a products and services on the basis of the activities undertaken to produce each product or service" (Horgren *et al*, 2000).

4. Analysis of Construction Material Logistics Cost

Before costs can be determined through ABC, a thorough understanding of the logistics activities and their relationship to ABC must be developed. The major construction logistics processes that facilitate the flow of materials from the point of suppliers to the where they are consumed for work include (i) demand forecasting; (ii) bidding; (iii) inventory management; (iv) material handling; (v) transportation; and (vi) warehousing. Each of these general processes is a part of logistics process and in order to thoroughly evaluate the total cost of logistics activities, all related activities or sub-activities must be taken into account. Based on the understanding of the construction logistics process the relationship between processes and the major logistics costs becomes more evident (Lin *et al*, 2001).

The major logistics costs can be categorized as (i) inventory carrying costs; (ii) procurement costs; (iii) order processing costs; (iv) transportation costs; and (v) warehousing costs (Lambert *et al*, 1998). These costs occur during the logistics processes. Based on the ABC concept being adopted for analyzing the logistics cost in previous studies (e.g. Gooley, 1995; Henricks, 1999; Thomas, 1994), modifications are made to suit the cost analysis method in the construction logistics process and those distinctive steps. The results allow the planners to determine the lowest total logistics cost which can be used for building a project logistics system.

4.1 Building cost analysis team

During the cost analysis using the ABC approach, suitable persons shall be selected from all the parties in the logistics process. Those who understand and help manage the activities that consume the resources and those who have experience in analyzing cost information of each activity shall be involved. For a construction project, the team may include contractor's purchasing manager, project manager on site, planner, quantity surveyor, etc.

4.2 Analyzing construction logistics process

This step is to identify and classify the major processes within the logistics function. In this paper, the analysis is based on an investigation of a residential project in Hong Kong with extensive use of precast concrete units. The logistics processes are illustrated in the left part of Fig. 1.

4.3 Breaking processes into activities

This step of the implementation procedure is to distinguish any specific, resource-consuming activities within each logistics process. Breaking down the logistics process into as many as possible well-defined activities allows a better analysis of the cost of each process. As shown in the right hand side of Figure 1, the logistics process of procurement composes of activities performed by the contractor and suppliers. Contractor's purchasing department has to prepare the bidding documents (which decides the total quantities of materials, delivery schedule and quality requirement), administer the bidding process and negotiate with suppliers on the supply details. On the suppliers' side, they need to prepare the tender documents, negotiate the price, and mobilize their team for production. During the transportation stage, inspection is first carried out to ensure the right products are being uploaded. Materials are uploaded by a truck equipped with a jib and this truck will also be used to lift materials onto other trucks. After the materials have arrived on site, same procedure is carried out. Materials are unloaded and stored on the designated storage area where they are inspected by the contractor again.

4.4 Identifying the resources that the activities consumed

ABC system is used to uncover the costs of relevant activities that have been identified in the previous step. In order to discover the activities' actual cost, the resources consumed by each activity must be pinpointed. Depending upon the activity and the method used in the logistics process, different types of resources are consumed. Most resources in company can be divided into five major categories including the labor, materials, equipment, facilities, property, and capital (Brimson, 1991; Kaplan and Cooper, 1998). This paper considers the labor, equipment, capital and property. The activities consume in every logistics process are shown in Table 1.

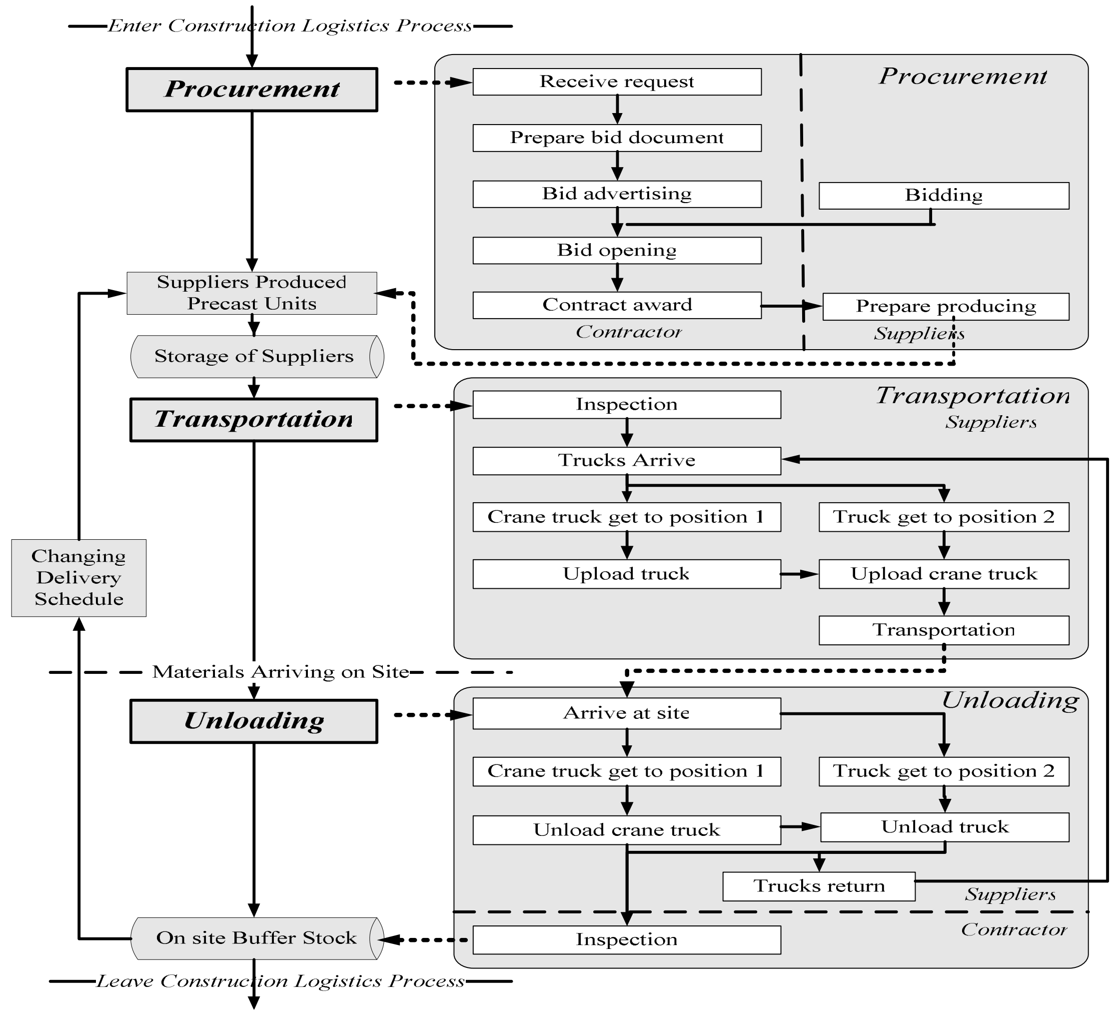

Fig. 1. Logistics Process and Activities of Construction Material Logistics Process

4.5 Determining the activities' costs

When the resources for each logistics activity are identified, the cost of activities can then be determined. In ABC, meaningful cost data shall be obtained to show the relationship between the activity and the way in which resources are consumed (Brimson, 1991; Kaplan and Cooper, 1998; Develin, 1999). Table 1 shows the unit cost of resource that is consumed during the construction logistics process and activity cost when multiplying the unit cost with the quantity consumed by the activity.

4.6. Analyzing the cost of logistics process

Based on the investigation at construction site and the analysis in Table 1, the logistics cost (*K*) during the material acquisition can be classified into six categories, *viz*. (i) procurement cost; (ii) storage cost at supplier's warehouse; (iii) transportation cost; (iv) unloading cost; (v) storage cost on site; and (vi) penalty for any changes in delivery schedule.

$$K_{Logistics} = K_{Procurement} + K_{Storage(S)} + K_{Transportation} + K_{Unloading} + K_{Storage(C)} + K_{Penalty}$$

Table 1: ABC for construction material logistics

Logistics Process	**Category**	**Resource**	**Cost of Resource**	**Cost of Activity**
Procurement	Labor	Staff in bidding	Pay rate	• Pay rate× Working time
	Equipment	Printer, papers, fax, telephone	Depreciation rate	• Depreciation rate × Order quantity × Unit cost
	Capital	Traffic cost	Traffic cost rate	• Traffic cost rate × Order quantity × Unit cost
Storage (S)	Labor	Administrator	Pay rate	• Pay rate× Working time
	Equipment	Shelf	Depreciation rate	• Depreciation rate× Store time
	Property	Warehouse	Rent rate	• Rent rate × Storage quantity × Store time
	Capital	Capital cost frozen in inventory, insurance, loss	Opportunity cost rate Insurance rate Loss rate	• Opportunity cost rate ×Storage quantity ×Unit cost × Store time • Insurance rate × Storage quantity ×Unit cost • Loss rate × Storage quantity × Unit cost
Transportation	Labor	Truck driver	Pay rate	• Pay rate× Working time
		Inspector (Supplier)	Pay rate	• Pay rate× Working time× Delivery times
	Equipment	Trucks	Rent rate	• Rent rate× Working time or Rent rate× Distance
	Material	Oil	Oil consumed rate, oil cost	• Oil consumed rate× oil cost × Distance
Unloading	Labor	Truck driver	Pay rate	• Pay rate× Working time
		Inspector (Contractor)	Pay rate	• Pay rate× Working time× Delivery times
	Equipment	Trucks, Crane	Rent rate	• Rent rate× Working time

	Material	Oil	Oil consumed rate, oil cost	• Oil consumed rate× oil cost × Distance
Storage **(On site)**	Labor	Administrator	Pay rate	• Pay rate × Working time
	Equipment	Shelf	Depreciation rate	• Depreciation rate× Store time
	Capital	Capital cost frozen in inventory, insurance, loss	Opportunity cost rate	• Opportunity cost rate ×Storage quantity ×Unit cost × Store time • Insurance rate × Storage quantity ×Unit cost • Loss rate × Storage quantity × Unit cost

The procurement cost can be decided and will not be changeable when the pay rate and work hours of staff in bidding, depreciation rate and machine hours, cost for negotiation are known. As for the storage cost at the supplier's warehouse, the administration fee, capital cost, issuance and loss can be decided when those rates and total material quantities are known and will not be changeable. However, the capital cost, allocated warehouse rental cost and equipment depreciation cost may be changed according to the storage time and quantities of every batch. Transportation fee will increase when the delivery frequency (*delivery times*) increases as it could lead to more inspection and preparation times. For the contractor, inspection occurs every time materials arrive on site. The cost of this mainly relates to the inspection and should be included in the materials logistics cost. More frequent delivery schedule will also increase the unloading cost with more inspection required before the materials can be accepted.

Storage at supplier's warehouse, transportation by suppliers, unloading work can be seen as the services offered by suppliers (i.e. $K_{Service\,Cost} = K_{Storage(S)} + K_{Transporation} + K_{Unloading}$). The sale cost and service cost constitute the materials cost for the contractor ($K_{Material} = K_{Sale} + K_{Service}$).

Regarding the storage cost, except for the capital cost and the allocated equipment depreciation, the other costs can be decided when those rates and the total material quantities are known and not changeable. Capital cost and allocated depreciation cost will change according to the storage time and quantities of every batch. The cost of changing the delivery schedule is not described in Table 1 as it is not an activity nor would it consume any resources. It may just appear in the contract and has to be decided at the procurement stage. Here, it is assumed that the penalty cost is decided as a certain number in the contract. When penalty occurs, this part of cost will not change along with other factors. Some studies refer this cost as the re-order cost and include such cost in the cost of carrying stock (i.e. inventory cost) (Waters, 2003). This paper tries to differentiate it from the stock carry cost as any change in the delivery schedule will lead to a change of the entire logistics method rather than the inventory cost alone.

Furthermore, the logistics cost being paid by the supplier and contractor shall be analyzed as whoever paying the cost it will be included in the material acquisition cost and allocated to the end customers. The purpose of this research is to lower the logistics cost of the entire supply chain rather than a particular part only. The profit generated by any reduction in logistics cost will be shared by the parties involved in the whole supply chains in a long run.

4.6 Finding main affecting factors to logistics cost

According to above cost analysis we can identify the construction logistics cost that will be changed with different delivery times, storage time and quantities when other parameters are determined. Storage and transportation become the main determining processes. They are the two pairwise factors changing in opposite directions. Lowering storage on site will lead to a higher transportation cost as any increase in delivery frequency will raise the cost of inspection and preparation before uploading at the warehouse and unloading at site. However, the material storage time and quantity will decrease in every batch leading to a decrease in storage cost.

Currently, planners estimate the delivery frequency and size according to their experience and the work schedule, while cost is seldom considered and quantified when making such decision. The work schedule is a determining factor for delivery planning and may affect the logistics cost. During construction some works in the schedule are flexible. Different time schedule will lead to different material requirement and ultimately have effects on the logistics cost. In the following section, the relationship between the time factors such as the delivery schedule and the work schedule with construction material logistics cost will be analyzed, and simulation will be carried out by means of the Genetic Algorithms (GA) approach. As there are many simulation method to derive the optimal results, this paper select GA just as a tools to achieve the objects.

5. Model Simulation

Simulation method is used here to help generate efficient work schedule and delivery schedule by minimizing the logistics cost and increasing the chance of on time completion. The start time of the activity, storage time, quantity, delivery frequency and quantity are the variables in this model. As an initial attempt of the GAs simulation, this paper only focuses on the work start time, delivery frequency and quantity while the other affecting variables will be considered in the next stage.

GAs is a self-adaptation optimization technology based on the genetic and evolution concepts (Holland, 1975; Goldberg, 1989). To fit this algorithm into model simulation, two assumptions have been made as the precondition of this research:

- The penalty cost is not being considered so as to simplify the model formulation, and hence the project manager can change the delivery schedule according to construction progress without considering any shortage in material supply.

- As this model emphasizes on minimizing material logistics cost, it is assumed that a change in the work schedule will have no impact on the critical path and hence the overall construction period.

Except the above basic assumptions, the following conditions are derived for simulation at the current stage. These conditions are used for the convenience of fitting the model variables into the simulation process.

- The quantity of distribution is the same each time, while the frequency of delivery is determined by $q_1 = q_2 = \ldots = q_i = \ldots + q_n = \frac{\sum_{j=1}^{D} R}{n}$; in which R is the daily resource consumption and D is the total working period.

- The delivery interval is separated by the delivery times equally.

The start time of an activity (T_{is}) affects the material consumption and must satisfy the following:

$$T_{iES} \leq T_{is} \leq T_{iLS}$$

$$\max\{T_{js} + t_j\} \leq T_{is}$$

Where T_{iES} is the activity's earliest start time; T_{iLS} is the activity's latest start time; T_{js} represents the start time of all preceding activities; and t_j is the activity duration. The equation requires the activity to begin before the latest start time but after the earliest start time, and an activity cannot begin until all the preceding activities are accomplished. A suitable activity start time will give perfect resource consumption curve which will result in the lowest cost.

Distribution variable concerns the number of distribution (n) from suppliers' warehouse to the site, i.e. $0 < n \leq D$. This variable decides the time to supply the materials to site in order to avoid any over-stocking or otherwise materials shortage from occurring. The optimal material acquisition cost and delivery schedule of a project schedule based on the eight construction activities in Sun (2004) are found.

Table 2: Working Schedule

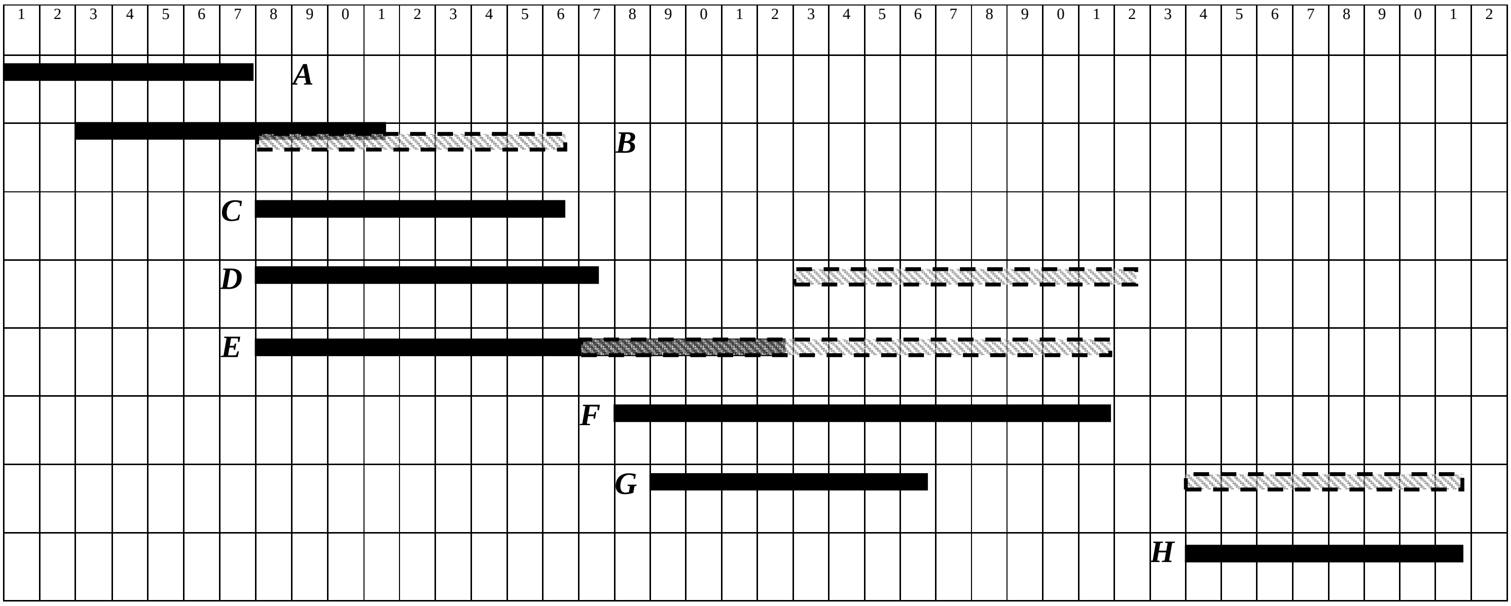

Table 2 shows the work schedule of the project. According to the analysis, the resources consumed by Activities A-H per day are 600, 300, 500, 400, 300, 700, 600, and 400 respectively. The total quantity of resources consumed during the construction is $\sum_{i=1}^{n} q_i = \sum_{d=1}^{42} R = 42{,}500$. The variables in this model include the activity start time (T_{is}) and the delivery frequency (n). The start time of Activities *B*, *D*, *E* and *G* are considered as variables as they have flexible time. Here, $\boldsymbol{T_{is}}$ is an integer matrix, where $T_{iES} \le T_{is} \le T_{iLS}$; and $T_{BS} \in (0,8]$, $T_{DS} \in (8,23]$, $T_{ES} \in (8,17]$, $T_{GS} \in (19,34]$. Besides, n is an integer, where $0 < n \le D$; $n \in (0,43]$. In this study, 40 individuals and 30 generations were set for the simulation. The individuals get closer to an optimal result as the generations evolve. The minimal logistics cost is $21,730 and the variables for this result is (T_{BS}, T_{DS}, T_{ES}, T_{GS}, n) = (1, 9, 13, 32, 41) implying that when Activities *B*, *D*, E and G are beginning at the 1^{st}, 9^{th} 13^{th} and 32^{nd} days respectively with the material distribution according to the daily delivery until the 41^{st} day, the material acquisition cost would be the least. The material to be delivered on site is 1,037 items per day.

6. Conclusion

A large amount of literature exists discussing the strategic role of logistics in creating value and its relationship to a company's financial performance. As reported by Richardson (1995), logistics controls a significant amount of assets and has direct impact on cash flow and that could add value through continuous productivity and service improvements, and possesses a strong relationship with a firm's customer service level and revenues. This research is an initial step towards an integrated construction logistics modeling and simulation. Based on the ABC theory, the construction logistics cost can be analyzed in detail and the relationship between the schedule arrangement and logistics cost can also be established. The material logistics model in the paper is based on the just-in-time concept where no off-site warehouse exists. The outcomes of this initial study lay an important foundation for further research. Further research will focus on the study of delivery schedule along with different quantities and intervals, penalty or extra cost for any changes in delivery schedule, and the effect on critical path caused by the changes in work start time. The actual data of every item in the logistics cost function will be collected through a comprehensive case study on site.

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