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An Analogy Based System to Track Material Management on Site

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Abstract – The most commonly used method for space management in the construction industry is the development of site plans. While these plans outline how to manage material deliveries, staging areas and crane locations for construction job sites in suburban areas, they are inadequate for those in congested, urban areas. This study focuses on the floor-level construction material layout which is required for multiple-floor building where multiple construction works occur simultaneously in close proximity. By minimizing excessive repositioning of construction materials, the floor-level construction material layout would assist in finding sufficient space for construction materials in urban areas where space is limited around the building sites.

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I. INTRODUCTION

Materials management comprises the system for planning and controlling of all efforts necessary to ensure that the correct quality and quantity of materials are properly specified in a timely manner, are obtained at a reasonable cost, and are available at the point of use when required. According to statistics, construction materials generally consume about 40 percent to 60 percent of total budget of the project. Therefore, it is necessary and important to properly manage and control construction materials. As such, several unneeded expenses could be substantially reduced.

To manage construction materials, many functions are typically performed, the most important of which is the ordering/purchasing of materials. This function first requires that all material needs are accurately specified prior to the submission of purchase orders (POs). The ordering/purchasing of materials, then, comes down to the informative answering of the following two questions:

(1) When to submit an order?

(2) How much to purchase?

Based on the two answers, the complete schedule for the purchasing and delivery of the concerned materials could be determined.

This is by no means a simple task. On one hand, ordering materials with large quantities at early dates of the project execution leads to financial losses due to costs associated with inventories. Even worse, materials may deteriorate during storage or be stolen unless special care is taken. On the other hand, ordering materials late can cause late delivery, thus leading to material shortage, work interruption and consequently delays. If this happens, the contractor will be forced to pay delay penalties to the client.

Material management systems in construction projects have generally been less addressed in the literature compared to their counterparts for industrial facilities. That study cited some practices that could be incorporated into construction material management systems from those known to industrial facilities. Nonetheless, the construction industry still has its peculiarities that hinder such smooth transition of knowledge. One of the biggest obstacles is the varying nature and needs of construction activities from one period of the project to another, which is very much unlike the common industrial operations. This differing nature and needs require a more complex mechanism for order optimization and inventory control.

Publications in the past two decades primarily focused on the general discussion and introduction of successful and unsuccessful practices of material management in construction projects. Also, there have been some recent attempts to sophisticatedly address aspects significant to materials management in construction projects. For instance, introduced an object oriented approach for material management in construction project. Caron et al. (1998) presented a simplified model to plan the delivery of materials to building projects, which could be used in early project planning stage. Researchers established indicators for the measurement of effectiveness of material management systems. They conducted an exploratory study of the effect of material inventory buffers, being a fundamental parameter in any material management system, on project performance. Also applied conventional optimization methods for steel rebar production and supply operations to a construction project from supply chain perspective.

Yet, there is still a need to have systematic procedures and tools to comprehensively perform the challenging task of managing and optimizing material purchasing and inventory control in construction projects. Two decades ago, identified several concerns and needed research topics for the area of material management in construction; the first research topic being the development of a systematic framework for deciding on the quantities and the timing of procurement for construction materials. Unfortunately, construction researchers have not addressed this topic as extensively as its importance would suggest. As such, this paper introduces an evolutionary system based on the mechanics of genetic algorithms (GAs) for material delivery optimization, which is directly linked with construction schedule. Furthermore, a computerized tool is presented with an illustrative practical example of a recent construction project. Other publications by the authors will follow to address other complementary aspects of the same topic, such as, uncertainty of delivery lead times and optimizing order process and timing.Construction materials management

Materials Management Cycle

Construction materials vary from simple items purchased by direct POs to complex tasks that are purchased by sophisticated contract forms. In all cases, several functions and steps comprise the material management process. Each of these functions can give rise to potential problems that need to be solved by the materials management department. Figure shows the sequential steps of materials management normally carried out by such department. In all these sequential steps, preparing the PO and delivery of materials constitute the cornerstone of the entire process.

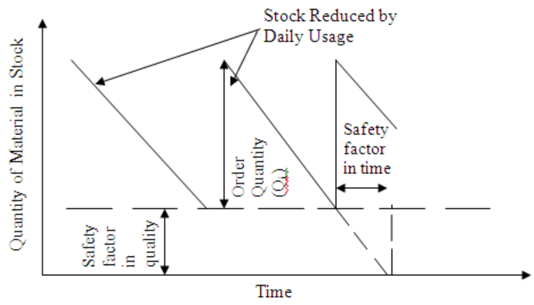

Figure No 1: Illustrative inventory control chart

Material Delivery and Inventory Control

After a PO for a construction material is being submitted to the selected supplier, a period of time, usually called “delivery lead time,” elapses before the actual delivery of materials to the project warehouse takes place. Once materials are delivered, they represent an inventory used during the construction process. In this context, inventories can be regarded as materials stocked to cover upcoming future demand. Since, inventories cost the construction firm whenever the inventory level is more than zero, inventory control is applied to minimize such cost and the various other costs associated with construction materials.

Figure shows an inventory control chart, as the ones typically used in industrial and manufacturing practices. As noticed, inventoried materials are depleted to satisfy the existing project demands. Meanwhile, new material deliveries are made at specific points in time to compensate for such depletion. Furthermore, due to the uncertainty of lead times, safety stocks are commonly instated to counterbalance any late materials delivery and keep production non-stopped.

There are several schemes for making material orders, such as, the cyclical or fixed order interval system, just-in-time (JIT) approach, material requirement planning (MRP) systems, and fixed order quantity system. While all of these schemes are used abundantly in industrial practices, they are mostly crippled in the construction industry with the exception of MRP systems. Simply put, an MRP system maintains the project’s material delivery schedules based on the forecasted needs, which are derived from the master plan and its bill of materials.

GA optimization model for materials management

The Pre-Optimization Process

Prior to running the optimization process for project material requirements, the project scheduling and preparation of MRPs should first be carried out. In this context, the project schedule is performed using any of the known commercial software. Afterwards, the MRPs for the considered material types are prepared, as explained in the subsequent paragraphs. The result of such step is a MRP array for each studied material.

Preparation of an MRP is somehow similar to developing resource usage profiles, as shown in Figure. The steps of preparing the MRP are as follows:

1. The project duration is divided up into equal time units, e.g. days, weeks, etc.

2. For each time unit in the project duration, the working activities are identified.

3. In any time unit under consideration, the needs for a given material are obtained by summing up the needs for such material in all working activities in that time unit, according to the following equation:

$$MRP_i = \sum_{j=1}^{k} r_j \times S_{ij} \quad \text{..... (1)}$$

where: MRPxi is the material requirement for time unit (i); rj is the material requirement of activity (j) per unit time; sij is a Boolean variable that takes either 0 or 1 depending on whether activity (j) is carried out at time unit (i) or not; K is the number of activities that uses this material.

1. The total needs for that material in the entire project can then be calculated by summing up the needs in all time units constituting the project duration, according to the following equation:

$$MRP_t = \sum_{i=1}^{D} MRP_i \quad \text{..... (2)}$$

The above steps are repeated for each material in the project. The material

Management system uses these outputs, i.e. the MRPs, to manage the flow of materials into the project store and out to the construction site. It is to be noted that while dynamic MRPs that take into consideration the float characteristics of project activities are a valid approach for material planning and optimization, the paper would assume that a proposed project schedule with predetermined activity execution times are made available before the preparation of the MRPs. Thus, each material would be associated with an individual MRP for all subsequent material planning and optimization stages.

The GA Optimization Process for Material Deliveries

Materials are delivered to site according to POs made. Therefore, any PO should account for when and how much of a certain material need to be delivered to project so as to optimally satisfy its material needs. The GA engine performs such an optimization task based on the MRP data for the materials under consideration and the different costs associated with material delivery and inventory, as shown in Figure 8.

To adapt the GA engine to handle the specifics of material deliveries and inventory problem, three GA elements were thoroughly studied; they are:

1. Chromosomal representation;

2. Fitness evaluation or the objective function; and

3. Genetic operators and termination condition.

Economic ordering quantity

The success of a company or business relies on many factors. One is its ability to efficiently manage product inventory, especially when inventory is in the millions of dollars and occupies space over many warehouses in many cities. Efficient management ensures that the costs of acquiring and storing inventory are minimized while the number of products in inventory is maximized. While enormous costs will accrue if inventory is ordered each time it is needed rather than stored, it is also uneconomical to store more products than there is space available. Storing too much inventory results in lost dollars, while storing too little may result in lost opportunities. These risks can be better managed by using proven inventory control methods. One such method is the economic order quantity.'5'

Each cost is based on the inherent risk of doing business. When it comes to inventory management, risks are ever present because of the inability to make exact predictions of demand, as well as cost fluctuations stemming from outside factors such as fuel and labor. It is almost impossible to eliminate all risks involved with inventory management, but they can be significantly reduced within the strict scope of determining an optimal order quantity. This chapter will illustrate an inventory management technique to contain risks, as well as how to calculate the typical costs involved.

Assumptions of the EOQ Model

The EOQ model is derived on the basis of a few assumptions.

- The first is that there is repetitive ordering. Once the company notices that inventory has been used up, another order will be immediately placed to replenish the stock. This will happen every time the inventory level depletes.

- The second assumption is that there is a constant demand for the product which occurs at a known rate. For example, if the company foresees a demand of 60,000 units per year, the demand during m months will be (60,000 m)/12 units.

- The third assumption is that there is a constant lead time, defined as the time between when an order is placed and when it arrives if an item has a lead time of two weeks, it will take two weeks for the order to arrive once it is placed. It also assumes there are no unforeseen delays in the delivery of the order, such as transportation or production delays. These simplifications make the calculations easier without resorting to complex calculus, and the results from more sophisticated stochastic analysis are often no better than those from this simple method.

- The final assumption of the model is that continuous ordering is employed. Inventory is constantly reviewed, and orders can be placed at any given time.

Weaknesses of the EOQ Model

The EOQ model is a powerful tool in inventory management, but it comes with its own sets of limitations. We will discuss a few of them in detail.

The first limitation is that the model will often present inconvenient order quantities. The EOQ will not always give a whole number; more often than not, it will suggest fractional quantities for items that are only available as discrete units. This becomes a concern when the items in question possess a high monetary value while occurring in small quantities. Another limitation is also related to inconvenient order quantities. Suppliers are normally unwilling to split standard-size packages. The EOQ model may also suggest that orders be placed at inconvenient points. It is convenient for companies to place orders at regular intervals, be it weekly, bimonthly, or monthly, for example. When the EOQ model is used, it may suggest that orders be placed at irregular times, such as every 5.25 weeks. This may be difficult for companies to efficiently schedule amongst their numerous other responsibilities, not to mention deciding what to do with the fractional week. Then there is the issue of transportation capacity. Real-world deliveries are made using vehicles such as trucks, ships, trains, and planes, all of which have fixed carrying capacities. The EOQ model's assumption that demand is constant can lead to an obsolescence of stock, besides being fraught with danger. Applying the EOQ without proper regard to falling demand, for instance, can lead to a high inventory level, meaning excessive carrying costs. To alleviate this problem, demand should be evaluated regularly and the EOQ adjusted accordingly. In the end, it is important to address and structure uncertainty to fit the EOQ model.

II. LITERATURE REVIEW

[1] This research aims to develop a cloud-based safety information and communication system for improving safety performance of infrastructure projects. The Map Safe system functions include Pre-Starting Safety Meeting Recording, Permit to Penetrate Request and Approval, Job Safety Analysis, and Safety Incident Reporting. The system was tested by using a road construction project and the results show it is a robust system that can be applied to improve safety. The key contribution of this research includes mapping the processes of safety information collection, analysis and approval, and pointing out the way for future application of cloud computing in construction safety management.

[2] This paper presents a novel framework that integrates the visual tracking into the detection of construction workforce and equipment. The integration significantly improves the recall and meanwhile maintains high precision. The proposed framework has been tested in real construction jobsites. Although it does not process the jobsite videos in real time yet, the test results showed that the recall for the detection of construction workforce and equipment was improved by more than 30–50%, while maintain the precision at the same level.

[3] This study presents a novel approach for developing a knowledge map for construction scheduling. According to framework-based classification, this study utilizes a science-specific search engine to search for literature on construction scheduling knowledge. Search results are then used to develop a file cabinet knowledge map consisting of a contour map, and several trend and density charts. This map representation compensates for the lack of various meanings in a single knowledge map. For novices interested in learning construction scheduling knowledge, results of this study provide constructive information to know the key issues and research trends in the construction domain.

In summary, this study presents a suitable procedure for extracting knowledge from public knowledge sources for development of a knowledge map. The proposed approach can be used for rapid generation of knowledge maps.

[4] This study investigated the feasibility of a WiFi-based indoor positioning system for construction sites. The system was developed using the fingerprint method of Received Signal Strength Indication (RSSI) from each Access Point (AP). A series of experiments were conducted at a shield tunnel construction site in Guangzhou, China. The results showed that the WiFi-based indoor positioning system was accurate within 5 m of error for that site, thus proving the utility of the system for tracking the approximate locations of labor at construction sites. Additionally, this system could be used for monitoring the locations of other construction resources such as vehicles and materials.

[5] The use of BIM technology in the implementation of new buildings has been successful, in recent years becoming an essential tool for facilitating the process of design, implementation and use. Improving solutions and developing new models allows effective control of the process of erecting buildings using BIM and allows for elimination of sensitive processes. Some disadvantages might be evident in instances where existing facilities, built without the use of recent advancements in this field, need to be either rebuilt or refurbished. An analysis was conducted to find the suitability of BIM technology in relation to an existing building where down force was needed be applied due to change of process and the need for installation of a new condenser in a roof space where weight was about 1.5 times higher than in the original equipment.

[6] The construction schedule management in the traditional mode will be affected by the natural environment, the objective environment and the subjective environment, leading to the interruption or obstruction in the construction process. But in the actual construction process, through assisting the BIM model and BIM5D software in the construction schedule management, not only ahead of schedule can be aware of the next step schedule of the required resource requirements, equipment demand and capital requirements; but also in the actual construction process Timely monitoring the progress of the completion of the percentage of the plan, the actual use of the amount of funds accumulated and the amount of budgetary funds deviation and so on; at the same time in the actual construction process can form a set of complete construction schedule management mode that timely supervising the construction quality and safety issues, recording defects on the spot, integrating data and associating model, timely rectifying or Repairing defects, and then checking the project.

[7] Construction site conditions are dynamic in nature, involving numerous activities and resources scattered on a usually congested site. Planning and availability of material laydown area on construction sites is an essential activity for every project. This paper presents the development of a BIM-based dynamic model for site material supply that is capable of identifying optimal dynamic scheme for the solution of this problem—what (material), how many, when, and where. The method of 4D modelling is investigated, as well as the acquisition method of site information, and the optimal scheme generation method. Contributions include the development of the BIM-based model for site material supply management, and a case study for the process of the site supply scheme implementation.

[8] This study seeks to identify the potential employment of that technology focusing on RFID for materials management in construction projects. As a precursor to this work, a literature review on materials management and exploring RFID technology potentially being employ in materials tracking was conducted. In conclusion, the findings reveal the needs for more sophisticated materials management solutions to improve on-site materials tracking and inventory management processes in the future.

[9] Based on a series of individual and focus group interviews, this paper reports construction professionals perceptions of the utility of the different visualization methods. Simultaneously exposed to three types of scheduling of the same building, construction professionals evaluated their ease of use and usefulness. This was done based on the Technology Acceptance Model, which explains how individuals develop an intention to use technology. Based on this work we found the three scheduling methods having strengths and weaknesses. Gantt provides the simplicity

and responsiveness required for the day-to-day communication in projects, and was perceived as the easiest to use. Flow line was perceived as less intuitive; however, some argued that it provides a better overview when many different work activities need to be run concurrently. 4D BIM has the clarity required for conveying the bigger picture, yet was perceived as most useful for early project stages. Our contribution to the body of literature is that we compare the technology acceptance of new and existing scheduling methods in order to unearth their complementary roles. This work is important for managers deciding on a combination of planning tools, enabling them to better run their projects.

III. CONCLUSION

Development of both order and delivery schedules in the industrial sector depends on the so-called "economic order quantity (EOQ)" model. This model represents a mathematical method for determining the number and magnitude of equal orders to be made over a specified period of time. This method assumes that demand is relatively constant, which is very untrue in construction practices. To enumerate, the EOQ model typically includes limitations such as:

- The demand variations are not accounted for.
- Both quantity discounts and price changes are not accounted for.
- The stock-out costs are not taken into consideration.
- Constant safety stocks are required throughout the time period considered.
- Maximum stock limitations are not typically incorporated in the model.

As such, the EOQ model can be dealt with from the perspective of some preliminary approach for material ordering and delivery planning in construction projects, rather than a comprehensive model for optimizing such plans. In fact, there is a need for a model that considers all variations in the construction material purchasing and delivery process and its associated costs.

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