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Automated multi-objective construction logistics optimization system

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ABSTRACT

Construction logistics planning entails the coordination of supply and site activities by integrating their decisions and recognizing existing interdependencies to minimize the total material management cost. Despite the preliminary estimates of its benefits to the construction industry, few contractors adopted logistics management because of its demand for detailed data and decision of material supply and site operations. This paper presents the development of a new automated multi-objective construction logistics optimization system (AMCLOS) that would support the contractors in optimally planning material supply and storage. AMCLOS provides a holistic framework of automatically retrieving project spatial and temporal data from existing scheduling and BIM electronic files, seamlessly integrating relevant contractor and suppliers' data, and optimizing material supply and site decisions to minimize total logistics costs. The performance of AMCLOS was validated against a previous construction logistics planning model, which provided useful insights on material supply and storage logistics in congested and spacious sites. The developed system is envisioned to increase the implementation of logistics management practices and early integration and coordination of construction supply and site processes.

1. Introduction

Logistics is defined as the efficient transfer of goods from the source of supply to the points of consumption in a cost-effective way while achieving acceptable level of customer satisfaction [10]. In the construction industry, logistics management implies the coordination between material suppliers and contractors to integrate and optimize the supply and site operational decisions [16]. Few construction companies have adopted logistics management, but preliminary studies estimate that 10% to 30% cost savings can be realized if efficient logistics management practices are implemented [2,17]. One possible reason for the limited implementation of logistics management in construction is the fragmented nature of the industry and the need to integrate and compile large amount of material logistics data [11]. Examples of these material logistics data include timings and capacities of supplier deliveries, transportation modes of material deliveries, construction activities demand, and site space availability. Manual integration of these data is a cumbersome task because of their complex interdependencies that dynamically change with the progress of the construction project.

A number of research studies have been performed to investigate the application of logistics in the construction industry. Caron et al. [3] developed a stochastic model to plan the delivery of construction material to building sites considering the variability of the delivery dates and construction productivity rate. The developed model integrates the supply and construction phases at the aggregate level, but it does not generate a detailed logistics plan. Agapiou et al. [1] presented a conceptual model of construction logistics to manage the flow of materials from the suppliers to the installation onsite. This study highlighted the need to manage and control material logistics in early project phases with emphasis on effective interfaces among project participants (designers, contractors, fabricators, and suppliers), exchange of information, and extension of company's processes outside of its organizational boundaries based on partnership agreements. Wegelius-Lehtonen [21] presented a performance measurement framework for construction logistics that classifies its metrics based on their focus and purpose. Another study by Jang et al. [7] reported the significance of five main factors on project managers' satisfaction of construction logistics: personnel, material flow, schedule adherence, contractor's organization, and information flow. That study also reported that their survey responses highlighted the need for additional improvement in construction logistics technologies and software. Sobotka [15] proposed a simulation modeling approach to optimize reengineering of internal logistics systems in construction companies and evaluate improvement alternatives of material and information flows in order to minimize logistics costs (ordering and carrying costs). Said and El-Rayes [11] developed logistics optimization models for spacious and congested sites that integrate material supply and storage decision to minimize total logistics costs incurred in all stages and possible increases in schedule criticality. The applicability of the aforementioned studies and realizing their potential benefits depends

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on the availability of automated systems that efficiently integrate all required logistics data. Accordingly, there is a need for automated logistics management systems that are capable of integrating construction supply and operational data and generating optimal logistics plans. These systems should enable automated retrieval of logistics data that are already produced and stored in digital files, such as construction schedules and building information models (BIMs).

This paper presents the development of an automated multi-objective construction logistics optimization system named “AMCLOS”. The main objective of the system is to provide practical and automated support for construction planners in optimally planning material supply and storage. To this end, AMCLOS is designed and implemented to provide a number of new and unique capabilities, including: (1) automated detection and retrieval of exterior and interior spatial data of the construction site from already available design electronic documents, such as building information models (BIMs); (2) expedited retrieval of schedule data from commercially available project planning software packages; (3) seamless integration of project spatial data that facilitates the definition of various types of spatio-temporal linking and storing all input data in a relational database; (4) utilizing multi-objective optimization and computational algorithms in order to simultaneously minimize total logistics planning and project schedule criticality; and (5) interactive data input and reporting of generated optimization results.

In order to provide the aforementioned capabilities, AMCLOS is implemented in Microsoft Visual Studio C++ programming Environment in five main modules, as shown in Fig. 1: (1) construction logistics planning module that formulates the optimization decisions, objectives, and algorithms that are considered in generating material supply and site logistics plans; (2) site spatial data retrieval module to facilitate automated identification of site exterior dimensions and building geometric attributes, which exist in the IFC (International Foundation Classes) file of the project's building information model; (3) schedule data retrieval module to import construction activities, materials, activities relationships, and activities-material assignments from commercially available project planning software packages such as Microsoft Project; (4) relational database module to provide seamless integration of site space schedule, and logistics data and detect any inconsistencies in spatio-temporal linkages defined by the planner, and store all defined data in a shared database; and (5) graphical user interface module to facilitate the input of project spatial, schedule, and logistics data and the reporting of generated optimal logistics plans. These five main modules and the system validation are described in more detail in the following sections.

2. Construction logistics planning module

The objective of the construction logistics planning (CLP) module is to integrate and optimize material supply and site layout decisions in order to minimize project total logistics cost and schedule criticality. The CLP module requires planners to represent the project timeline as successive stages that represent major changes in space demand and material supply of construction activities. The CLP module classifies site space into interior building spaces (i.e. rooms) and exterior site-level space that is represented as discrete grid locations [12]. In cases of congested construction sites, scarce exterior space obligates the use of interior building spaces for material storage, if needed. Interior building space is made available by pushing construction activities beyond their early times to accommodate material storage [18]. Accommodating interior storage would reduce material supply costs, but will increase project schedule criticality because of shifting interior construction activities. Accordingly, the proposed system models construction logistics planning as a complex multi-objective decision making problem that requires the use of innovative optimization techniques to generate optimal logistics plans that represent different balances between minimizing logistics costs and minimizing schedule criticality. As shown in Fig. 2, a genetic algorithms (GA) tool, named NSGA-II [4], is used to implement the multi-objective optimization of construction logistics planning, which considers four categories of decision variables:

- Noncritical activities scheduling decision variables are modeled as the minimum shifting days (S_i) of noncritical activities that can range from 0 day to the total float (TF_i) of each noncritical activity i. These decision variables are used to identify the optimal shifting of noncritical activities beyond their early times to generate more interior space for material storage while considering imposed interior space constraints, which include: room capacities, creation times of rooms, and permissible periods of interior material storage.
- Material supply decisions include the Fixed-Ordering-Period for every material m in each construction stage t ($FOP_{m,t}$), which define the fixed time periods between material deliveries with variable quantities to satisfy construction schedule needs [11]. The possible value of the Fixed-Ordering-Period can range from 1 day to a maximum number of days that are specified by the planner. A Fixed-Ordering-Period

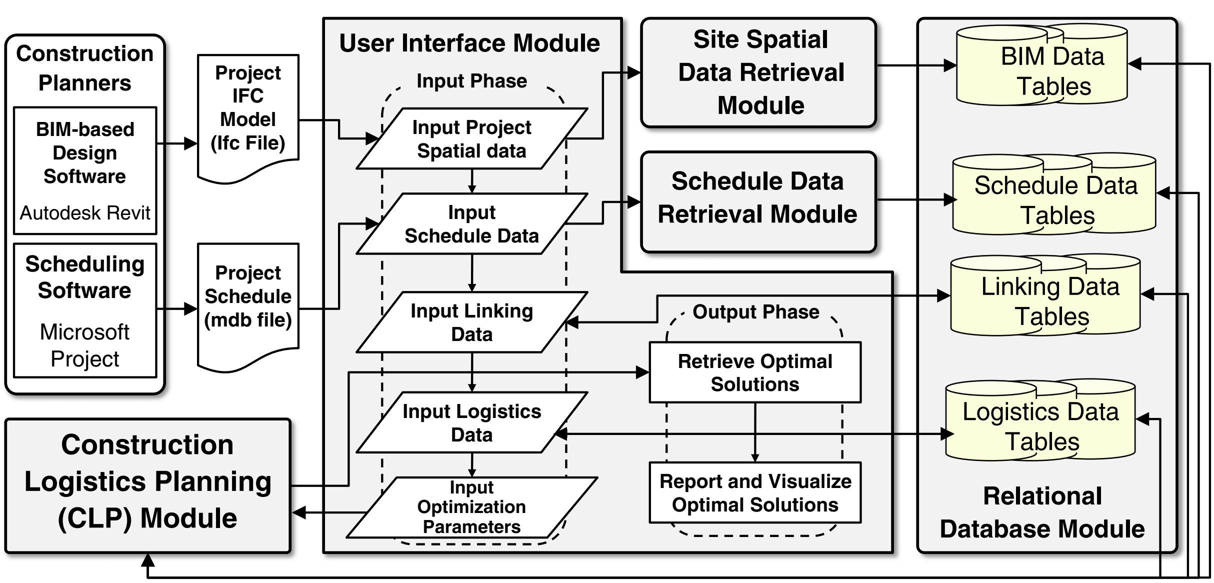

Fig. 1. AMCLOS main implementation modules.