SUPPLY CHAIN DESIGN FOR MODULAR CONSTRUCTION PROJECTS

Pei-Yuan Hsu[1], Marco Aurisicchio [2] and Panagiotis Angeloudis [3]

1 BACKGROUND AND IDENTIFICATION OF PROBLEM

The construction sector is currently undergoing a shift from stick-built construction techniques to modular building systems. If construction supply chains are to support this transformation, they need to be modified and strengthened using an adapted logistics system. Building materials in modular construction projects are initially transported to manufacturing facilities where they are transformed into modular products. This process is absent in traditional construction projects. Furthermore, these modular products are often large in size. Thus for construction sites with limited storage space, warehouses are needed to temporarily stock products. In these contexts, the structure of the construction supply chain is altered, because it now possesses the characteristic of both construction and manufacturing.

The logistics of modular construction also includes aspects that distinguish it from the generic supply chain. For example, modular products such as bathroom and kitchen pods often are tailor-made and project-specific. Hence, they normally cannot be procured from other manufacturers when the production fails to meet the demand. Also, the total production quantity of modular products produced should match the demand from the construction sites, and consequently, the inventory will reach zero when a project ends. Furthermore, additional assembly processes and costs are required after the products are delivered to final customers (construction sites). Therefore, previous studies on integrated supply chains can only partially inform a new logistic model for modular construction as additional features have to be considered. A key issue in a three-tier modular construction logistics - including a manufacturing factory, a storage facility, and construction sites - is understanding how to integrate the various elements/stakeholders of the supply chain seamlessly.

2 RESEARCH AIM AND METHODOLOGY

The aim of this research is to develop a mathematical model to specify the optimal configuration for the logistics of modular construction, which reveals the best manufacturing rate, schedule and initial inventory level for multi-products needed on multi-construction sites under various demand profiles so that the demand can be fulfilled at the lowest cost and with minimal waste. Under this circumstance, the logistic system can remain competitive, and in alignment with the goal of lean construction.

This research proposes a Mixed Integer Linear Programming (MILP) model that captures construction scenarios with demands for modular products that are either foreseeable or abruptly disrupted. In addition, the model anticipates that delays may occur at sites during construction. The objective function of the model is to minimise the overall operational cost of the supply chain, which includes the costs of production, transportation, inventory and assembly.

[1] PhD Student, Dyson School of Design Engineering, Imperial College London, UK, p.hsu15@imperial.ac.uk

[2] Senior Lecturer, Dyson School of Design Engineering, Imperial College London, UK, m.aurisicchio@imperial.ac.uk

[3] Senior Lecturer, Department of Civil and Environment Engineering, Imperial College London, UK, p.angeloudis@imperial.ac.uk

3 Research Findings

The MILP model has been tested in a case study involving delivery of bathroom pods to a new hospital project in Scotland. The model outputs the most favourable production scheme and initial inventory level needed to serve multi-construction sites.

We have developed two versions of the model instance to deal with two demand profiles. The first version is to address foreseeable demand variations in construction sites. In this study, the weather factor is used as an example. Weather is a widely accepted delay factor in construction, and modern technology makes its prediction quite accurate. Our model can help a factory set up the best weekly production plan based on weather forecast (Table 1).

Table 1: Output for the foreseeable disruption scenarios

Date	June 23		June 24		June 25		June 26		June 27	
Pod type	A	B	A	B	A	B	A	B	A	B
Expected demand	--	--	11	8	8	5	5	5	0	0
Production rate	--	--	6	4	7	4	5	4	0	0
Inventory level	6	6	1	2	0	1	0	0	0	0

The second version of the model is to deal with abrupt demand variations on sites. Accidents inevitably happen, and a logistic system must be able to respond in the shortest time (Table 2). Our model imitates the real situation, in which the production plan is not changed until the very next day after the disruption, due to insufficient changeover time in the factory. The model thus can be of great help to managers whose responsibility is to make decisions for production planning in a short time frame.

Table 2: Demand and output for the original and abruptly disrupted scenario

Day	0		1		2		3		4		5	
Original Scenario (no-delay)												
Pod type	A	B	A	B	A	B	A	B	A	B	A	B
Demand	--	--	12	12	12	12	12	12	--	--	--	--
Production rate	--	--	6	6	6	6	6	6	--	--	--	--
Inventory level	18	18	12	12	6	6	0	0	--	--	--	--
New Scenario (abrupt disrupted)												
Demand	--	--	12	12	6	6	6	6	6	6	6	6
Production rate	--	--	6	6	6	6	2	2	2	2	2	2
Inventory level	18	18	12	12	12	12	8	8	4	4	0	0

The three-tier logistics structure investigated in this research is absent in stick-built construction projects. The most favourable responses in the manufacturing factory and the storage facility following demand variations at construction sites have never been studied. The model established in this research, which finds the optimal configurations for the supply chain of modular construction, can serve as a basis for decision making.