

# Applying Kanban System in Construction Logistics for Real-time Material Demand Report and Pulled Replenishment

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## Abstract –

Drawbacks of the absence of the flow view in the conventional construction logistics planning gain more attention. Inefficiency and wastes (e.g., on-site overstock) in the construction logistics caused by adopting an avoidance strategy is recognized. Meanwhile, the unstable labour productivity and periodic planning method cause difficulties for adopting Just-in-Time (JIT) approach in construction. As a real-time control system of a production flow with the ability of rapid and precise acquisition of facts, the Kanban system can be a solution for a pulled production and related logistics. This paper explores how to apply Kanban concept to record the material consumption, report the real-time demand and trigger a material replenishment from off-site to on-site. A methodology of designing and applying Kanban batch in the digital construction logistics with Building Information Modelling (BIM) systems or tools is proposed. A case study of an infrastructure project is carried out to address the functions and performance of a Kanban-triggered material replenishment. The results of the case study show significant savings of site storage area and construction time by applying Kanban concept in the construction logistics.

## Keywords –

Kanban; Construction Logistics; Pull; Real-time Demand; Building Information Modeling

## 1 Introduction

For a long time, buffering is a conventional solution to prevent adverse effect of off-site material supply disruptions in the construction field [1,2]. However, it may cause problems, e.g., additional waiting time, an excessive amount of orders, overstock on-site, waste of site capacity as well as difficulty in materials and related equipment maintenance [3]. To reduce buffers and remove wastes from the construction process, lean production approaches such as Just-in-Time (JIT) are

considered useful [4,5]. However, the unstable labour productivity and periodic planning method cause difficulties for adopting JIT production in the construction field.

The original Kanban system is well-known as a JIT control system, but its application is not limited to JIT production. The essence of the Kanban system is characterized as a real-time control system of a production flow with the ability of rapid and precise acquisition of facts [6]. A conventional construction logistics plan adopts a short-term demand forecast based on managers' experience and expertise. However, most information systems for construction logistics cannot capture this kind of demand forecasting results because of limited data. Developing the knowledge bases and sophisticated algorithms can help transfer the knowledge in this specific field from the person to the computer. Based on it, real-time analysis, adaptive buffering, proactive scheduling and automated decision-making for construction logistics are realizable. From an operational perspective, the equilibrium of material consumption, on-site stock, and off-site replenishment is essential for construction logistics at the current stage. To address this point, adopting the Kanban concept is helpful for information systems to capture the real-time material consumption amount and replenishment demands precisely and timely.

This paper explores how to apply the Kanban concept to record the material consumption, report the real-time demand and trigger a material replenishment from off-site to on-site. First, a literature review regarding Kanban system and construction logistics planning is conducted to trace back the theoretical foundation. Meanwhile, experiences are drawn from current construction planning practices. Afterwards, a methodology to design and apply Kanban batch in the construction logistics with 4D Building Information Modelling (BIM) systems or tools is elaborated. An infrastructure project is finally studied and simulated to address the functions and performance of a Kanban-triggered material replenishment.

## 2 Literature Review

### 2.1 Kanban System

The Toyota Motor Corporation developed the Kanban system with order cards to control production flows because the cost of adopting the computerized system was huge in the 1970s [6]. As the development and maintenance costs of information systems gradually decrease, many manufacturers implemented electronic Kanban systems. Junior and Filho (2010) did a review and classified variations of Kanban systems into systems which follow the original Kanban logic and systems which do not [7]. Systems using the original Kanban logic have the following features:

- Use of two communication signals, i.e., production and transportation signals;
- Pulled production;
- Decentralized control;
- Limited WIP, i.e., finite buffer capacity.

By comparison, variations beyond the original Kanban logic emphasize one or several following aspects:

- Variable maximum inventory level;
- Signal use modification;
- Gathering and using the information;
- Functioning;
- Materials release.

Nowadays, the manufacturing industry has adopted a series of mature production information systems or software packages using original, partially or entirely modified Kanban logic. In the AEC field, Kanban-like or Kanban-type methods are frequently mentioned in lean construction research, addressing the pull concept and visual control of construction workflows. Tserng et al. (2005) proposed a Kanban-like visual control system for project participants to manage construction supply chains [8]. Sacks et al. (2009) introduced Kanban-type pull signals in BIM-based environments to improve the transparency of construction workflows [9]. Dave et al. (2016) adopted control principles from Kanban to fulfil the visual controls in a lean construction management system using BIM [10]. However, most of the Kanban signals applied in construction serves as a visualized process status (e.g., finished, delayed or under construction), rather than the demand-driven, i.e., pull production trigger, which is the essential part of the original Kanban system.

### 2.2 Construction Logistics Planning

According to current practices, the construction logistics plan is generally made according to construction managers' experience and expertise. It involves an as-

designed site-layout, project QTO (Quantity Take-off) and a series of periodic (e.g., daily, weekly, monthly) schedules [11]. It adopted periodic planning of material consumption, and site storage areas are configured according to the periodic consumption. Another essential feature of the current construction logistics planning is that materials and building components are treated as input or constraint of a certain construction task from a construction workflow or schedule [11]. The completion of the target construction task is the highest goal and any shortage of on-site material stock should be avoided. Therefore, problems about excessive amounts of orders, waste of site capacity and difficulty in materials maintenance etc. may occur. Two aspects should be taken into account regarding current construction logistics planning:

1. Uncertainty caused by periodic consumption, i.e., short-term demand forecast based on experience and expertise;
2. Inefficiency and wastes (e.g., on-site overstock) caused by adopting an avoidance strategy to ensure sufficient material resource for construction workflow.

Considering the aspects mentioned above, Last-Planner System (LPS) provides a pull concept using the "Should-Can-Will-Did" pattern and weekly meetings regarding construction workflows and schedules [11]. It helps to correct the deviation between as-planned and as-built progress and to reduce the uncertainty of a short-term demand forecast. Meanwhile, approaches, e.g., Advanced Work Packaging (AWP) and location-based management improve construction scheduling and workforce developing [12].

From an operational perspective, the equilibrium of material consumption, on-site stock, and off-site replenishment is essential for the two aspects above. It does not emphasize the robust of the construction workflow itself but requires a clear production flow [13]. Every construction task can be treated as a discrete production, where precise real-time material consumption can be reported as evidence of future demand. It is the essence of the Kanban signal in a pulled production. Compared to LPS or AWP, the Kanban system is more appropriate to deal with material flows rather than construction workflows. The reason is that the material flows are not sensitive to on-site discrete production and unstable productivity.

Simulation techniques support the analysis of material and information flows in construction. As Law described, material and information flows for analysing supply chains are suitable to be defined as a simulative system [14]. Modelling and Simulation methods e.g. discrete event simulation (DES) and agent-based simulation (ABS), have been continuously developed in

the field of the construction logistics, to analyse and optimize logistics processes and configurations [15].

The original Kanban system contains complete rules and principles, which companies, e.g., SAP (System Applications and Products) and Oracle already adopted into the ERP (Enterprise Resource Planning) system or supply chain information system. It is also possible to introduce it into BIM-platforms which adopting Industry Foundation Classes (IFC). Building models with higher LOD (Level of Development) can provide abundant detailed information for the construction logistics. For example, LOD 400 contains information required for fabrication, assembly and installation [16]. Meanwhile, 3D visualization with Model View Definitions (MVDs) is helpful for collaborative product development from design to on-site construction. Digital construction sequencing and scheduling techniques and current 4D BIM practices [17] [18] [19] provide a foundation for the adoption of the Kanban signals to report real-time material consumptions. It is essential to not only provide a visual Kanban board or tool with 3D representations but also help change a periodic and centralized construction logistics planning into a real-time demand-driven logistics management.

### 3 Methodology

#### 3.1 Overview

This paper draws experiences from current construction planning practice, including the long-term planning, short-term periodic scheduling, and site storage planning [12] [17], as shown in Figure 1:

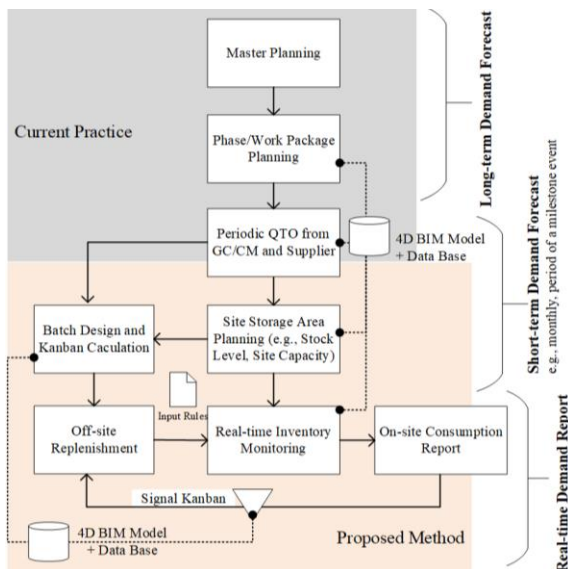


Figure 1. Logistics planning method combined with current construction planning practice

In the proposed method, the following aspects are emphasized:

**Long-term demand forecast** addresses the project objectives, i.e., overall cost, schedule, and quality goals. It involves mater or milestone planning, phase or work package planning, and project QTO. It follows the conventional construction project management and is conducted in the project early phase.

**Short-term demand forecast** addresses the periodic planning, i.e., weekly, monthly or within a milestone event's duration. The general contractor, construction manager, trade manager (if any) and suppliers work out periodic QTO documents and Kanban batch size collaboratively. These periodic QTO documents are fundamental for the on-site store area configuration.

**Real-time demand report and pulled replenishment** adopts the Kanban signal as the trigger of off-site replenishment. Suppliers collect Kanban signals and arrange their production and replenishment activities according to the real demand. Every material batch can be tracked along the whole process using a Kanban barcode or RFID (Radio-frequency identification) and assigned to its area. Therefore, it is possible to achieve a decentralized on-site stock monitoring.

**4D BIM** provides adequate LOD (level of details) building or construction component models, model-based QTO and related construction processes.

Applying the Kanban signal does not mean JIT production or zero stock. The Kanban signal is adopted as a real-time demand indicator for the off-site replenishment and site stock monitoring. It does not apply for every kind of material resource. The target material type has two features: 1) produced off-site and 2) with a certain level of site stock.

In the following sections, the critical activities in the proposed method to apply the Kanban system in construction logistics will be elaborated: 1) Kanban batch design; 2) site storage area planning and initial Kanban deployment; 3) real-time consumption record, real-time demand report and pulled replenishment.

#### 3.2 Kanban Batch Design

The first step of introducing the Kanban system into construction logistics is to design the Kanban batch size associated with periodic QTO at the short-term demand forecast stage. This paper provides a BIM-enabled example to explain how to work out a consensual periodic QTO and Kanban batch size from both supplying and consuming sides. The collaborative workflow is presented in Figure 2:

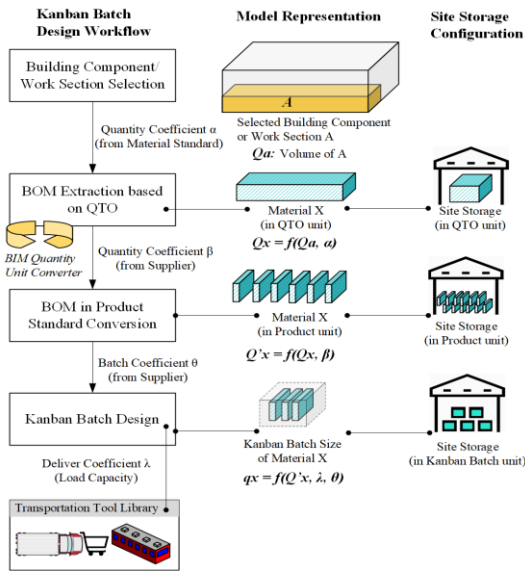


Figure 2. Workflow of Kanban batch design

**Building component/work section selection:** it depends on the short-term planning objectives, e.g., for a milestone event or a monthly plan. In this example, the building component or work section A is chosen, and its principal material is material X. The QTO extracted from the BIM model provides the volume of A ( $Q_a$ ).

**Bill of Material (BOM) extraction based on QTO:** according to  $Q_a$  and quantity coefficient  $\alpha$  from the material standard, the quantity of material X ( $Q_x$ ) can be calculated, and a BOM list can also be generated when there is more than one kind of materials.

**BOM in product standard conversion:** a BIM quantity unit converter (see Figure 3) is applied to convert the unit of quantity of material X from QTO into a product standard or a customized standard, which is provided by suppliers. The contractor can choose BIM objects and submit material quantity information to the calculator as an input, and suppliers can send product information to the server as another input, then a product quantity is worked out as the output.

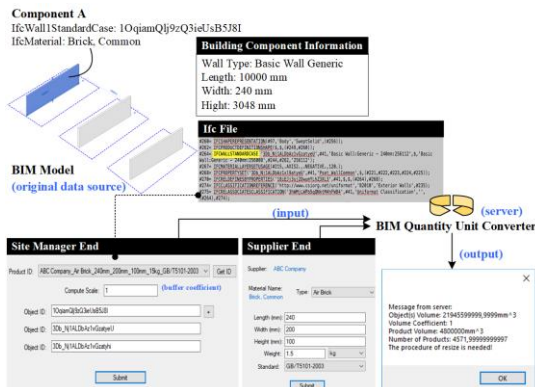


Figure 3. Example of BIM quantity unit converter

**Kanban batch design:** the Kanban batch size means the least lot size in the pulled material flow, e.g., a container capacity or a customized package capacity. It is the basic unit for consumption reporting, ordering, and material delivery and mainly decided according to suppliers' production (coefficient  $\theta$ ) and transportation (coefficient  $\lambda$ ) conditions.

### 3.3 Site Storage Area Planning and Initial Kanban Deployment

An adequate initial area of site storage is crucial for the execution of the Kanban system. For a certain type of material e.g., material X (see Figure 2), GC/CM or material manager should provide total material consumption quantity ( $Q_c$ ) extracted from QTO and target construction duration ( $T_c$ ). It is necessary to achieve an agreement about the storage duration ( $T_s$ ). Besides, the non-uniform coefficient ( $\sigma$ ), quantity-to-area convert coefficient ( $\epsilon$ ) and site utilization factor ( $\mu$ ) should be obtained according to technical standards. The initial area of site storage (see Equation (1)) can be calculated as:

$$S = \frac{Q_c * T_s * \sigma}{T_c * \epsilon * \mu} \quad (1)$$

Meanwhile, the supplier needs to provide the product standard or sufficient design information i.e., the quantity coefficient  $\beta$  (see Figure 2), to convert the initial total stock quantity from the material unit ( $Q_s$ ) into the product unit ( $Q_k$ ) (see Equation (2)). According to the initial value of stock quantity  $Q_k$  and Kanban batch size  $q_x$  (see Figure 2), the number of Kanban batches ( $N$ ) can be further calculated (see Equation (3)):

$$Q_k = f(Q_s, \beta) = f\left(\frac{Q_c * T_s * \sigma}{T_c}, \beta\right) \quad (2)$$

$$N = Q_k / q_x \quad (3)$$

### 3.4 Real-time Consumption Record, Demand Report and Pulled Replenishment

After the initial Kanban batches of material for the site storage are deployed on the construction site, the real-time material consumption can be recorded, and the discrete demand can be reported using Kanban signals. The information flow is illustrated in Figure 4:

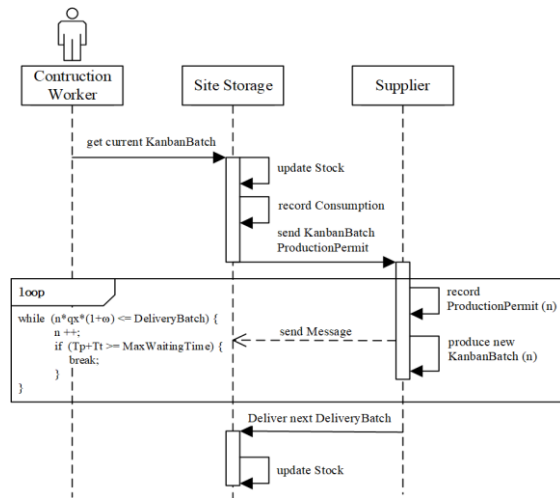


Figure 4. Information flow of real-time consumption record, demand report and pulled replenishment

Getting a KanbanBatch from site storage is a discrete event. When this KanbanBatch is taken out from the on-site storage, a production permit or an order of a new KanbanBatch is released to the supplier. It means that the supplier can know the real-time consumption of required materials. The supplier can collect discrete production orders and produces several new KanbanBatch according to his/her own delivery policy e.g., the minimum size of DeliveryBatch in this example. Meanwhile, the max waiting time of the construction site about the required KanbanBatch should be also taken into account, i.e., the MaxWaitingTime in this example. This paper adopts demand theories from Sugimori et al. (1977) [6] and adapts them into the context of construction logistics. Two discriminants for the loop of recording demands and producing new batches are set up (see Discriminant (4) and (5)):

$$n * qx / (1 + \omega) \leq \text{DeliveryBatch} \quad (4)$$

$$Tp + Tt \leq \text{MaxWaitingTime} \quad (5)$$

Here:

$n$ : number of KanbanBatch production orders;

$qx$ : Kanban size;

$\omega$ : buffering coefficient of container/package capacity;

$Tp$ : off-site production time;

$Tt$ : transportation time.

The first discriminant determines how many new Kanban batches should be produced according to the collected demands and the supplier's delivery policy. The second discriminant is a constraint condition of the lead-time, i.e., production time and transportation time. However, the tolerance for lead-time is sensitive to the on-site storage buffer level, material type and flexibility of construction schedule etc., and it should be developed further.

## 4 Case Study

The aforementioned method is employed for controlling the on-site stock of a river remediation project. The remediation project of Tantou River is located in Shenzhen city, China. It includes six sub-projects: 1) channel improvement; 2) culvert construction; 3) desilting work; 4) sewage interception; 5) spillway tunnel and 6) flood retarding basin improvement. The engineering-procurement-construction (EPC) contractor is Power Construction Corporation of China and Sinohydro Bureau 14 Co., Ltd. manages the project.

We take the section of Furong Road (K0+000 ~ K0+050) in the culvert construction sub-project (X0+000.00 ~ X1+192.021) as a case to study how to improve off-site warehousing and on-site stock configuration of culverts' main material i.e., steel bar with the type of HRB400 (16~25). In this case, we focus on applying Kanban signal to capture real-time consumption and adopt a pulled replenishment. It includes on-site storage area planning, initial stock deployment, and Kanban-triggered delivery. A BIM-enabled Kanban batch design is excluded in this case because standardized steel bars are used.

The duration of the target culvert construction section is 116 days and costs 13,862,112.17 in Chinese currency. The size of the culvert is 2.7x3.0 m and built with C25 reinforced concrete, as shown in Figure 5:

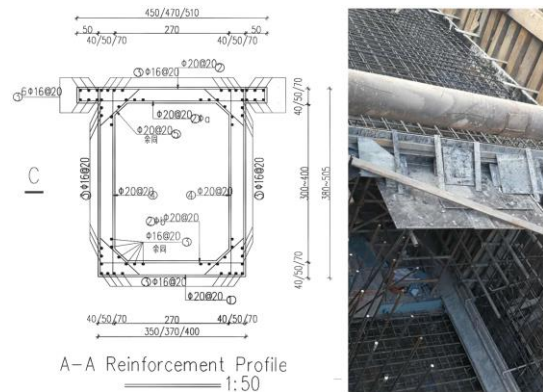


Figure 5. Culvert size and reinforcement profile

For this construction section, an off-site warehouse was set for steel bar storing and a on-site storage area with the size of 8x30 m was planned for weekly consuming. The distance of the off-site warehouse and on-site storage area was 3 km (see Figure 6). There are challenges in the storage and replenishing of steel bars:

- A large amount of steel consumption
- Unstable labor productivity
- Strict construction duration requirement
- Limited on-site storage area because the river flows through residential and commercial sectors

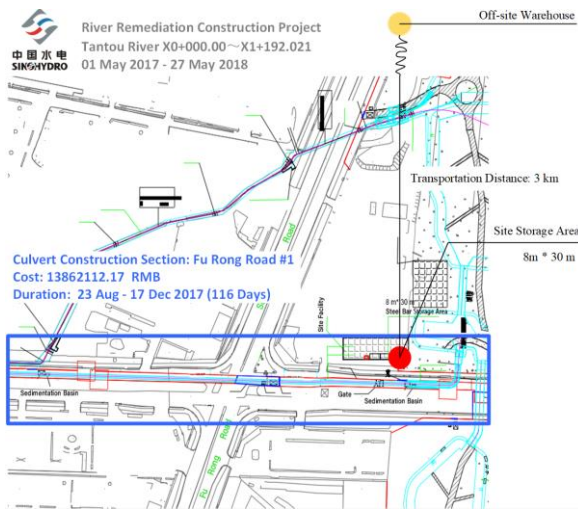


Figure 6. Project information and site layout

The site manager monitored the on-site storage of steel bars, and the replenishing plan of steel bar was delivered weekly from the off-site warehouse to the on-site storage area. Table 1 provides necessary information of steel bar site storage and replenishment. In this construction section, three problems related to site storage occurred and were reported by the site manager:

- Overstock on site in the earlier days
- Site stock shortages in the later days
- Construction delays caused by site stock shortages

Table 1. Steel bar site storage and replenishment plan

Plan Item	Number
Construction duration	60 days
Total quantity	458.83 t
Site storage area	240 m <sup>2</sup>
Initial site stock	180 t
Weekly replenish	30 t

To study the periodic on-site storage planning and the influence of the unstable labour productivity, a simulation was conducted. We adopted a distribution triangular (0, 20, 5.01) for the daily consumption of steel bars affected by the labour productivity. It was chosen according to the historical project data. The simulation results are shown in Figure 7:

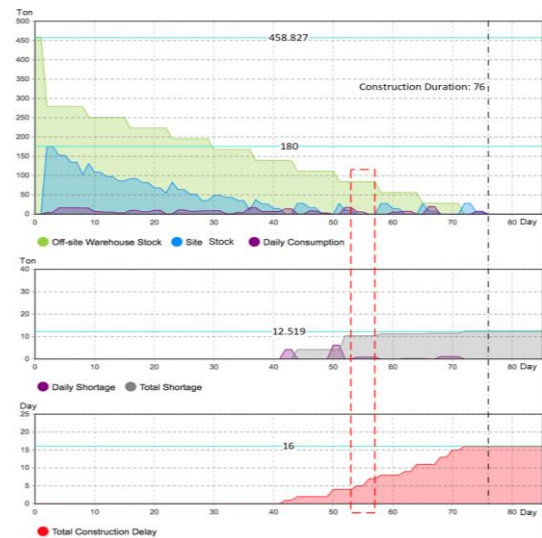


Figure 7. Simulation results of weekly replenishment

The simulation results show a construction delay of 16 days and some steel bar shortages. The results also show that, as the project progresses, even a minor shortage can lead to further delays in construction (outlined with dotted red line in Figure 7). The problem of overstock at the beginning is also obvious according to the simulation results.

To improve this situation, the Kanban signal is applied to report the real-time consumption, and another simulation was conducted. In this case, we treat the off-site warehouse as the supplier. The Kanban size design is simple in this case because standardized steel bars are used. The weight of each 12m long steel bar is 0.0145 t. A bundle with 100 steel bars is set as a package unit and its weight is 1.45 t. The Kanban batch size is designed as 20 bundles with a weight of 29 t. Table 2 shows key parameters of Kanban-triggered on-site storage and material replenishment planning:

Table 2. Parameters of Kanban-triggered replenishment

Parameter	Expression	Value
Site storage area	$S = \frac{Q_c * T_s * \sigma}{T_c * \epsilon * \mu}$	214.12 (m <sup>2</sup> )
Initial site stock	$Q'_s = \frac{Q_c * T_s * \sigma * \beta}{T_c}$	144 (t)
Package unit	1 Bundle = 100 steel bar	1.45 (t)
Kanban batch size	qx	29 (t) 20 (bundle)
Initial Kanban stock	$N = Q'_s / qx$	5

\* $Q_c = 458.83$ ;  $T_c = 90$ ;  $T_s = 30$ ;  $\alpha = 1.40$ ;  $\epsilon = 2.5$ ;  $\mu = 0.6$ ;  $\beta = 0.8$ .

The simulation results are shown in Figure 8. We adopt the same distribution for the daily consumption as

the weekly replenishment mode. Because of the real-time consumption report and Kanban-based delivery, all shortages and delays in the weekly replenishment (see Figure 8) mode could be avoided. Meanwhile, the initial site stock is saved from 180 t to 144 t, and the site stock maintains a stable level.

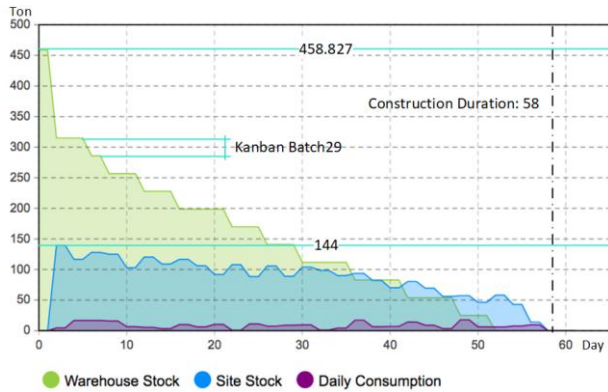


Figure 8. Simulation results of Kanban-triggered Replenishment

To explore the differences between weekly replenishment and Kanban replenishment, a comparison analysis is given in Figure 9.

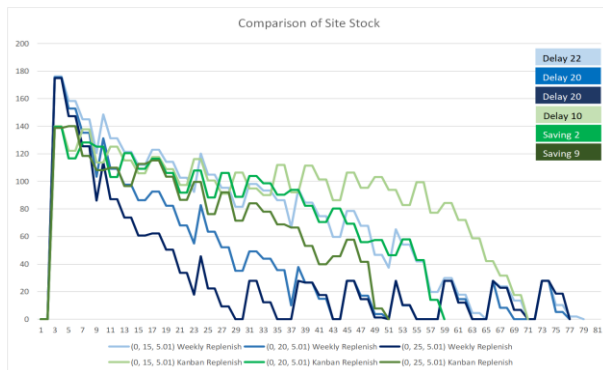


Figure 9. Comparison of site stock in weekly and Kanban-triggered replenishment modes

Three distributions of steel bar daily consumption are applied: triangular (0, 15, 5.01), triangular (0, 20, 5.01) and triangular (0, 25, 5.01). In the Kanban mode, on-site stocks are stable and the total construction duration is shorter when the daily consumption level is higher. Comparatively, in the weekly replenishment mode, the on-site stock is excessive in the earlier days and insufficient in the later days. The total construction duration can be longer even when an intensive labour input is employed, as additional construction delays occur caused by stock shortages.

## 5 Discussion

This study was initiated to seek a driving mechanism for efficient construction logistics planning aided by information systems. Besides rethinking of the Kanban system, this paper provided implications for future construction logistics related research:

**Essential Role of Digital Collaboration in Construction Logistics:** based on the proposed method and the results collected from the case study, it can be stated that digital collaboration between the supplier and the construction manager plays an essential role in the construction logistics planning and monitoring. The construction logistics requires both on-site information and off-site information. Transferring site activities into off-site supply chains is a trend. It is helpful for some types of projects, for example, projects near residential areas. It means accurate and timely off-site information is indispensable for the construction logistics management. Meanwhile, suppliers need more building information for their production schedule and quality control. All these aspects indicate that an efficient digital collaboration in the construction logistics is required. With the development of industry-specialized information technology e.g., BIM and the decrease of information systems costs, it is the time to consider a digital collaboration from both the supply and construction sides. The Kanban batch design, therefore, can be more convenient with the assist of digital collaboration. This kind of digital collaboration in logistics planning can also contribute to a long-term commercial partnership.

**Proactive Attitude toward Construction Logistics:** there are challenges cause by the unstable labour productivity on-site and it has great effects on the construction logistics. The construction manager of the case study project reported that there were overstocks on-site in the earlier days and site stock shortages in the later days. It indicates the drawbacks of the conventional buffering approach: 1) waste site capacity; 2) ignore the influence of oncoming labour productivity peak. Applying the Kanban concept can improve current situation by collecting real-time consumptions and converting them into demands. It can ease the pressure of stock consuming after a productivity peak by a quick-respond replenishment. When a forecasting procedure of the productivity is applied, a proactive control is possible for the construction logistics. However, it is still a long way to go for a proactive logistics management aided by accurate forecasting.

## 6 Conclusion

Unlike the manufacturing industry, the unstable labour productivity and periodic planning method cause

barriers for adopting concepts e.g., JIT production in the construction field. The original Kanban system is well-known as a JIT control system, but its application is not limited to JIT production. In this paper, a methodology of designing and applying Kanban batch in the construction logistics with 4D BIM systems or tools was proposed. The Kanban concept was highlighted to record the material consumption, report the real-time demand and trigger a material replenishment from off-site to on-site. A case study of a river remediation project was carried out with a focus on steel bar site consumption and off-site replenishment. The simulation method was carried-out to analyse different scenarios. The simulation results presents significant savings of on-site storage area size and construction time by applying the Kanban concept. Finally, a discussion and implications were provided for future research.

More efforts will be made to integrate theory with practice regarding Kanban in the construction logistics planning and monitoring. Further studies will address complete Kanban application in the construction field and explore the real-time demand forecasting with abundant data from both on-site and off-site sides.

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