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Design Guidelines For Digital Kanban Systems With High Service Level

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Abstract

One success factor of Kanban is its elegant simplicity for physical inventory control. However, especially in multi-variant productions inventory levels are digitally tracked. To maintain the high service levels of the Kanban systems, the digital representation in the ERP must reliably reflect the physical inventory levels and deviations should be detectable. The design of such a digitally tracked Kanban systems requires a booking logic and a method for deviation detection. Especially in multi-stage systems with several inventory levels, the design of a simple and robust Kanban logic is challenging.

Thus, the paper first gives an overview of existing inventory booking strategies. Based on the strategies the effects of inventory deviations on logistical performance in classic Kanban and digitally controlled Kanban systems are discussed. Design guidelines summarize the analysis. Subsequently, three different design alternatives of a classical, digital and high resolution Kanban system are developed. These guidelines and design alternatives should enable practitioners to setup reliable Kanban systems including their digital representation.

Keywords: Kanban; Inventory Management; Production Planning; Deviations; ERP

1. Introduction

A factor for the widespread use of Kanban as a production control system is its simplicity: An empty bin triggers the release of a new batch. A well-defined Kanban system support two main logistical goals:

- **Controlled inventory levels:** The fixed number of Kanban cards keeps the inventory levels in control. Overstock is not possible.
- **High service level:** Service level is the ability to instantly and completely fulfill a customer demand without waiting time. The constant availability of one or more filled Kanban bins supports high service levels without complex planning mechanisms. [1–3]

However, in multi-stage high-variety production the level of transparency in a classical Kanban is not sufficient as it lacks three critical functions for digital operations:

1. **Digital process triggers:** To start automated processes such as order creation, digital triggers are necessary. However, a physical Kanban system relies only on the transportation of the Kanban itself. To automate the processes, clear guidelines for triggers are necessary. [2,3]
2. **Digital inventory tracking:** The majority of quantitative approaches for inventory dimensioning and demand forecasting rely on time series data. A physical Kanban system does not support the tracking of inventory levels over time, as consumption data are not stored. Thus, a systematic way for inventory tracking of a Kanban system is needed. [1,3]
3. **Automated deviation detection:** Inventory deviations are often a high cost factor in production [4]. To detect regular (e.g. BOM-issues) or irregular (e.g. scrap) inventory deviations, a comparison

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between actual and planned quantities is necessary. As a physical Kanban is solely relying on actual inventory levels such an analysis is not possible in a classical Kanban.

The challenge is to keep the digital representation of the Kanban in the ERP-systems synchronized with the physical reality on the shop floor while maintaining the system's simplicity. To setup a digital Kanban system, several conceptual design questions (such as trigger points) must be answered to fulfill the above-mentioned requirements. Existing approaches focus on single elements of a digital Kanban system such as digital identification of booking. However, a systematic design approach is missing, leading to the following research question:

How can a simple digital Kanban system be systematically designed to enable digital inventory tracking and deviation transparency while keeping high logistical service levels?

Core of the paper are design decision to be made while setting up such a Kanban system. For the design, the system engineering's problem solving cycle is followed. [5] The first chapter describes situation and objective of the system. The second chapter searches for solutions while analyzing potential design decisions and summarizing the preferred options in design guidelines. [6] Chapter three analysis existing design approaches of Kanban systems and summarizes their limitations emphasizing the need for a new solution. Based on the preceding chapters, Chapter 4 develops the configuration options for Kanban systems and thus focuses on the synthesis of solutions as well as the selection of an appropriate solution. Chapter 5 shows the article's limitations and an outlook.

2. Kanban Systems

The chapter first describes the key elements of a Kanban system with a digital representation and discusses the challenges regarding high service levels. Based on the system description, the effects of inventory deviations are highlighted. For the three main design decisions booking verification, time and quantity design guidelines are synthesized.

2.1 Elements of Kanban Systems

Figure 1 shows the elements and functionality of a Kanban system in two layers: The actual physical flow of Kanbans as well as a possible digital representation of the inventory levels. The Kanban material flows from a warehouse (supply) to the work centers where the materials are consumed to produce finished goods. The production quantities are determined by production orders (demand). [1] When using a digital representation, two types of Kanban inventory have to be differentiated:

- **Shop Floor Inventory**: Quantity that is physically stored in a defined storage location (e.g. number of parts in Kanban bins).
- **ERP Inventory**: Quantity that is booked to a clearly defined storage location in the ERP system (e.g. number of parts in the locations labeled "shop floor").

In the Kanban system there is a distinct signal (trigger) that starts the Kanban cycle, i.e. releasing the delivery of a new batch of Kanban material. With two types of inventory, there are two feasible triggers [7,8]:

- **Shop Floor Trigger:** In classic TPS Kanban systems, a shop floor trigger initiates the Kanban cycle. Usually an empty Kanban box or a Kanban card represents the trigger. (Fig. 1a)
- **ERP Trigger:** In an ERP System, the trigger is raised when falling below a threshold inventory level (reorder point). (Fig. 1b)

Processes can be automatically initiated by using ERP triggers. However, this requires an accurate and timely representation of the shop floor inventory within the ERP system. The article discusses the deviations between shop floor and ERP inventory based on the following three questions:

- **Deviation effects:** How do deviations affect the on-time delivery of material supply (Fig. 1c) and production order release (Fig. 1d)?
- **Time**: How are changes in inventory levels recorded digitally for inventory tracking? (Fig. 1e)
- **Quantity:** What are causes for deviations between the shop floor and ERP inventory levels, and how can they be detected? (Fig. 1f)

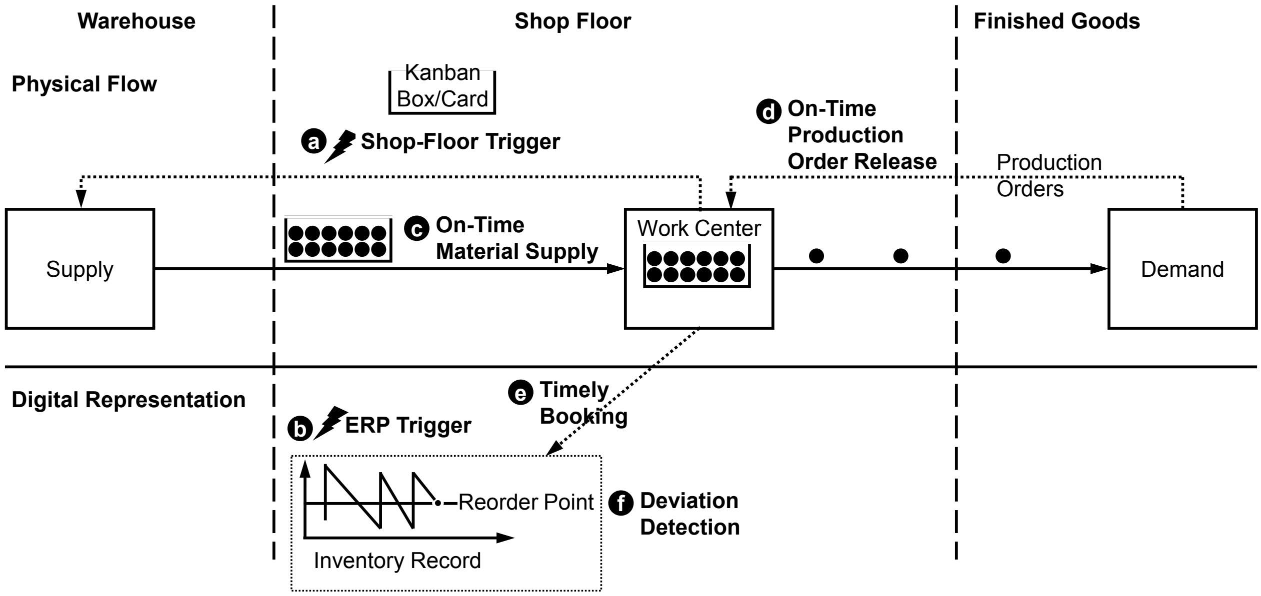

Figure 1: Elements of a digital Kanban system

2.2 Effects of Inventory Deviations on Logistical Performance

Depending on the selected type of trigger, the effects of deviations on material supply (service level) and production order release vary. Having always sufficient material is critical for the work center. If a material availability check is performed, having enough material is critical for a timely order release. Figure 2 summarizes the deviations effects (excessive inventory or inventory shortage) for the two trigger types.

	Shop-Floor Trigger		ERP Trigger	
ERP Inventory	Excess Inventory (ERP > Shop Floor)	Inventory Shortage (ERP < Shop Floor)	Excess Inventory (ERP > Shop Floor)	Inventory Shortage (ERP < Shop Floor)
Material Supply	Material supply on time	Material supply on time	Delayed material supply	To early material supply
Production Order Release	Order release no problem	Order release no problem	Release orders when parts are missing	Order approval is blocked, (thus inventory might be ok.)

Figure 2: Effects of inventory deviations on logistical performance depending on the trigger

Shop Floor trigger. The Kanban system solely relies on the physical inventory levels. Thus neither excessive inventory nor inventory shortage affect the on time trigger of material reordering. The availability check does not consider the physical Kanban. Therefore, any discrepancies in stock do not affect the order release. [2]

ERP trigger. If ERP triggers are used, inventory discrepancies generally have critical impacts. Excess inventory leads to delayed material delivery. These can cause material shortage at the workstation. Inventory shortage can lead to excessive material at the work center. Excess inventory in the ERP can lead to order release though material is not available at the work center. If the ERP inventory is less than the actual shop floor inventory level this could lead to holding back of production orders, even though material is available.

In summary, Kanban systems with shop floor triggers are resistant to inventory deviations leading to high service levels and on time order release. Kanban systems with digital triggers are sensitive to inventory deviations. However, a digital representation it necessary to analyze the causes of inventory deviations.

2.3 Timely Inventory Booking

To generate a digital representation in the ERP, it is essential to book inventory changes to timely reflect the actual inventory on the shop floor in the ERP system. There are two ways to book changes in quantity:

Verified booking: For a verified quantity, the physical measurement is accurately recorded using methods such as counting or weighing and entered into the ERP system. This can be achieved by either confirming or correcting the actual quantity and using the actual measured quantity as the nominal value.

Not Verified booking: For a not verified quantity, the specified or planned quantity is transferred to the ERP system without verification and becomes the nominal quantity. The specified quantity could be derived from a production order, a Kanban label or the bill-of-material, etc.

Clearly, verified quantities have benefits for the accuracy of the ERP system. However, any type of quantity verification and booking in the ERP system is associated with effort. Therefore, verification should be done at points where few bookings are required. This is usually at the entry to the workstation as full boxes are delivered making visual checks easier.

► **Guideline 1: Verified quantities:** Quantities should be verified, ideally at a point with higher quantities and a lower amount of transactions to reduce effort.

Figure 3 shows the four methods for inventory booking depend on the relative position to the actual date of consumption.

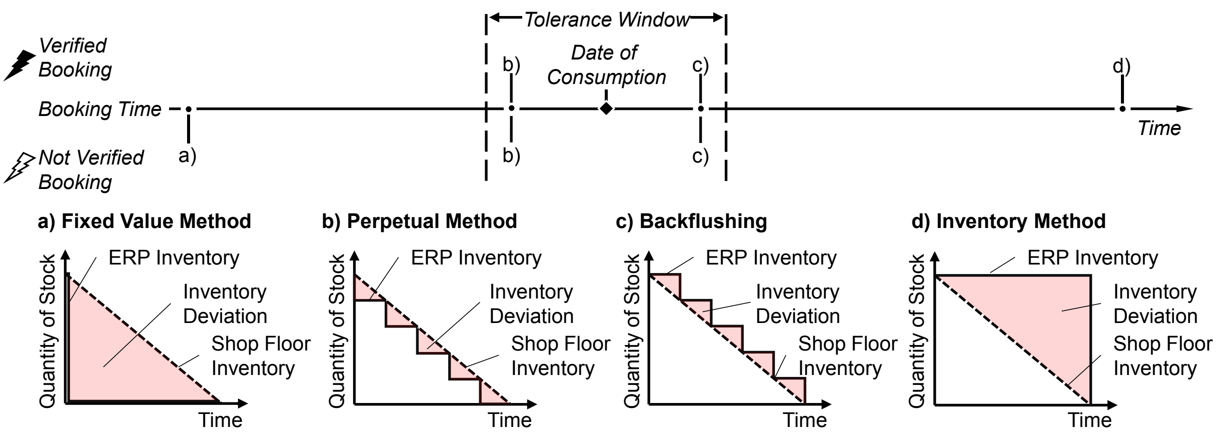

Figure 3: Classification of booking methods relative to date of consumption

Ex-ante bookings: With these methods, consumption is booked before the material is withdrawn. This type of booking often results in a shortage of inventory in the ERP system upon withdrawal, as booking occurs before material is withdrawn.

Using the **fixed value method** the material consumption in terms of quantity is immediately booked out as consumption. The method is usually not suitable for inventory management as the time delay and thus the inventory deviation is too big. Goods that are procured infrequently and for a specific purpose are possible exceptions. [9,10]

By using the **perpetual method**, material consumption is recorded via inventory accounts and material withdrawal slips, so the material consumption quantity is equal to the sum of all documented material withdrawals. The booking and the material consumption take place at the same time. [9,10] As the time delay is short and within a tolerance window, this method is suitable to record changes in Kanban quantities.

Ex-post booking: The other category covers delayed booking methods. Material consumption is booked after occurrence. This type of booking tends to result in excess inventory in the ERP system.

Backflushing determines the planned material consumption retrospectively based on produced quantities of finished products, by using bills-of-material. With this method, the planned consumption is booked after the actual consumption has been withdrawn. [9,10] As the time delay is short and usually within a tolerance window, this method is suitable to record changes in Kanban quantities.

The **inventory method** involves the withdrawal of material before it is booked, summarizing the quantity of material consumed for a period, e.g. monthly consumption of screws. [9,10] The inventory method is usually not suitable to record Kanban quantities as the time delay and thus the inventory delay is too big.

A small tolerance window not only enhances system stability but also improves data reliability, facilitating accurate conclusions. Additionally, adherence to the tolerance window enhances data reliability and enables the drawing of accurate conclusions. Systematically recording stock movements requires additional effort. Nonetheless, this additional effort is crucial to maintain synchronization between the shop floor and ERP.

► **Guideline 2: Timely Bookings:** Bookings of shop floor changes should occur within a narrow time window in the ERP system. The proverb "every movement results in a booking and every booking results in a movement" is a good shop floor facilitator for the guideline.

2.4 Deviation Detection

As shown above, deviation are especially critical when using ERP triggers. There are numerous reasons for quantity deviations. Knowing the total Kanban quantity (sum of all items in the Kanban bins) and using a physical trigger, two main reasons for deviation can be detected by analyzing the inventory trend (Figure 4):

a. **Decreasing ERP Inventory:** A decrease in ERP inventory occurs when the planned material consumption is higher than the actual consumption. This can be caused by over reported scrap or too high quantities in the bill-of-materials.
b. **Increasing ERP Inventory:** An increase in ERP inventory happens when the reported material consumption by ERP is less than the actual consumption. Causes are unreported scraps or consumption of parts missing in the bill-of-material.

The smaller the Kanban quantities, the smaller is the window for deviations and a fast deviation detection.

► **Guideline 3: Small Quantities:** The Kanban quantities should be as small as possible. This allows for a timely automated detection of deviations.

3. Existing Approaches on Deviations in Digital Kanban Systems

The literature review carried out used the bibliographic database Scopus to identify existing design approaches for Kanban systems allowing deviation detection. The search was conducted in November 2022 using the keywords "inventory", "deviation", "kanban", "method", "difference", "count", "cycle", "posting", "ERP", "MES", "control", "dimensioning" and "design" within title and abstract.

None of the papers found, focuses on the effects of inventory deviations and detection of deviations in digital Kanban systems. However, several papers are touching the research question. Thus the relevant papers are newly clustered as following:

- How does the **Kanban design** affect inventory deviations?
- How do electronic Kanban systems (**e-Kanban**) handle quantity deviations?
- How do **RFID** Kanban systems handle the time lag between bookings?
- How do systems derived from **accounting** deal with deviations and their logistical effects?

Kanban Design/Concepts. The enormous popularity of Kanban has led to a myriad of Kanban systems being used in today's industrial environment. These Kanban systems are adapted to the individual circumstances of production and logistics systems. [11,12] According to Kumar et al. [13] two general movements can be distinguished from literature. These two streams are Kanban empirical theory and modelling approach. Kanban empirical theory can be further divided into flow stope, assembly line and batch production system. The modelling approach can be divided into mathematical, queuing, markovian, simulation and cost minimization. [13] From their review of the literature, Akturk et al. [14], Kumar et al. [13] and Junior et al. [12] show that a large number of authors have worked on design and optimizing the parameters associated with improving the performance of Kanban. Dimensioning of the most appropriate trigger point in different systems is undertaken. However, there is a lack of investigation in the literature on what triggers the Kanban cycle and how deviations can be detected. [15–19] Even Li, who designs a robust Kanban system, neglects the aspect of inventory deviations. [20]

In summary, the literature on Kanban design is concerned with optimizing the parameters of a Kanban system. In addition to classical Kanban, special cases such as the ramp-up process, no constant flow rate are also considered. Trigger points for optimizing the quantities in the system are discussed in particular. What is missing, however, is the consideration of different triggers and, in particular, the recognition of deviations in the quantity. Furthermore, all of these systems have been designed for the use of physical triggers.

e-Kanban. E-Kanban is a form of modification from classical Kanban. Some authors are concerned about the dimensioning and optimization for the e-Kanban. [21,22] Considered from some authors is the technical implementation of e-Kanban in enterprises. [23] Several authors also deal with the integration of suppliers into e-Kanban. [24]

However, no author deals with the detection of deviations in the context of e-Kanban. Marikova [25] points out as a considerable problem in the introduction of e-Kanban the bad data quality and discrepancies in the data basis.

One approach to digitizing Kanban is called e-Kanban. Solutions for technical implementation and integrating external suppliers are considered. Inventory deviations are also not considered in these approaches.

RFID. Several approaches can be found in literature where RFID triggers the ERP system. [26,27] Some authors propose RFID Kanban systems. The focus of this approaches is the optimization of the information flow to reduce the inventory in the kanban cycle. [28–31] These approaches share the fact that the material movement is technically tagged and thus enables traceability through the processes. Due to the automatic action-based booking, there is no time delay in booking. However, these approaches do not deal with inventory deviations between ERP and shop floor.

There are many technical proposals for the use of RFID to track the movements of the inventory. How to optimize Kanban using RFID is also covered. Recording inventory movements without time delay is the advantage of RFID. The issue of discrepancies between the inventory in the ERP and the actual inventory is not taken into account.

Accounting. Inventory transactions and recording of inventory changes are clearly regulated by standards. Performing inventory at the end of the year is well described in literature. However, it is not considered how deviations between physical inventory and account inventory can be performed without delay. Haryono [32] deals with the deviation between physical inventory transactions and computing in accounting information systems only from the perspective of financial evaluation. Nonetheless, none of the authors have taken into account the impact on logistics. [33]

There is a good description of inventory taking. There are also approaches that deal with recording discrepancies. However, these do not consider the logistical implications.

Deficits of exiting approaches. Approaches to the design of Kanban systems are varied. There are different directions: Adapting Kanban to the given conditions, optimizing the approaches in terms of quantities and performance. However, no approach addresses deviations in general and between ERP and shop floor in particular. Neither do they consider the issue of different triggers. There is evidence that the literature partially answers the three research questions presented in this article. Nevertheless, no single approach addresses all of the research questions.

4. Designing robust, multi-stage Kanban systems

Based on the deficits of the existing Kanban system (Figure 1) and the derived guidelines the section develops three Kanban setups with increasing inventory transparency and digital functionality. The development is based on the classical Kanban system and incrementally increases the systems complexity. The three approaches are based on several analysis-synthesis discussions with industrial partners and production planners. This allows for a step-by-step transition of existing Kanban systems:

- The **classical Kanban** system implements an ERP trigger for material replenishment in the warehouse without deviation detection on the shop floor.
- The **robust digital Kanban** adds deviation detection on the shop floor to the system.
- The **high-resolution Kanban** additionally supports deviation detection for each work center.

4.1 Physical shop floor Kanban (Classical Setup) with digital reordering

The system consist of three logistical zones: Warehouse, Shop Floor and Finished Goods. Only within the warehouse, a digital inventory tracking is established (Figure 5).

A physically empty Kanban box (or card) triggers the material replenishment from the warehouse. When the refilled Kanban is transferred from warehouse to shop floor the Kanban quantity is booked out from the warehouse. Reordering from the warehouse is digitally triggered by the ERP inventory level.

As the shop floor inventory levels are not recorded, deviations cannot be detected automatically. As the system relies on physical triggers only, on time material supply and production order release due to wrong digital data is impossible.

The system is suitable for cheap items where deviations in consumption are uncritical (e.g. C-Parts, consumables) and product specific cost allocation is not necessary (e.g. same quantities for each product).

4.2 Robust and Simple Digital Kanban with Physical Triggers

The second solution extends the first solution by a digital representation of the shop floor inventory level. Materials consumed by production are deducted from the shop floor inventory via backflush (e.g. piece-by-piece based on bill-of-materials). (Figure 6)

The reorder of material from warehouse to the shop floor is still based on physical triggers (empty Kanban). When transferring the refilled Kanban from warehouse to shop floor the Kanban quantity is rebooked via transfer order from warehouse to shop floor.

As quantities are digitally represented on the shop floor, deviations can be detected on the shop floor according to section 2.4. However a precise identification of the exact work center causing the deviations is not possible, as all Kanban are represented by a single inventory level on shop floor level. Due to physical triggers, deviations do not affect the service level of the materials on the shop floor.

The system is suitable for expensive parts where deviations must be tracked. However, the identification of deviations (e.g. wrong BOMs) still requires manual effort. The identification might be delayed especially if the total Kanban quantity on the shop floor is high (e.g. an item is used in multiple work centers).

4.3 High-Resolution Digital Kanban with Inventory Trigger

The third solution extends the digital Kanban by a digital representation of each work center's inventory level and a bin-level tracking in the warehouse. This setup allows a precise tracking of the inventory levels and batches available at each location for each point in time. (Figure 7)

An empty Kanban triggers the physical replenishment from a FIFO controlled supermarket to the respective work center. A transfer booking from the supermarket to the work center reflects the consumption. From the supermarket, reorder bookings can be done with a digital trigger.

Inventory deviations can be detected timely and precisely due to the relatively small quantities. However the system requires additional bookings from the supermarket to the respective work centers.

The system is suitable for expensive Kanban parts where precise tracking is mandatory. Furthermore, the setup additionally support batch traceability, which is mandatory in industries like pharmaceutics.

4.4 Comparison and Validation

The three solutions built upon each other and thus allow a step-by-step refinement of the Kanban system. This approach supports the gradual refinement of an existing analog Kanban system to a high precision Kanban system.

All three systems maintain **controlled stock levels**. In case of classical Kanban, it is limited to the physical stocks. Having a digital representation the stock levels can also be controlled via ERP system. All systems have a high shop floor **service level** as the shop floor trigger is always physical.

The degree of digital inventory tracking and the support of digital triggers increase from the first to the third solution. The digital inventory tracking combined with BOM backflushing is basis for the automated deviation detection, which is possible in the second and third solution.

In an industrial use case (machine assembly with 50+ Kanban loops), the transition from a classical to a robust digital Kanban has been validated. Production planners highlighted the simple implementation as no additional inventory locations or changes in SAP R/3 were necessary. Operators confirmed the high service level as a simple physical trigger is used. The practitioners emphasized the importance of continuous inventory control as suggested in Fig. 4.

5. Discussion and Outlook

A digital representation of Kanban inventory is necessary to benefit from digitalization (e.g. automated triggers and processes). However, it is essential to manage deviations between digital and physical Kanban in order to avoid subpar service levels. This paper systematically describes the critical elements of Kanban systems and derives design guidelines for implementation.

Based on the design guidelines and existing approaches, three practical solutions are derived. The solutions are based on standard ERP functionality and the industrial applicability is validated in a motor production. Further research is needed in detailing the exact ERP requirements and the integration with other Industry 4.0 tracing and tracking methods.

This paper presents a systematic approach to solving a tangible material supply problem by digitizing existing Kanban systems, while maintaining service levels and simplicity with standard ERP functionality.

The high resolution Kanban enables complete traceability of single batches. Further research is needed to design robust procedures for batch traceability in Kanban systems. Batch traceability is mandatory in many high quality industries such as medical technology and cannot be reached with existing Kanban systems.

Appendix

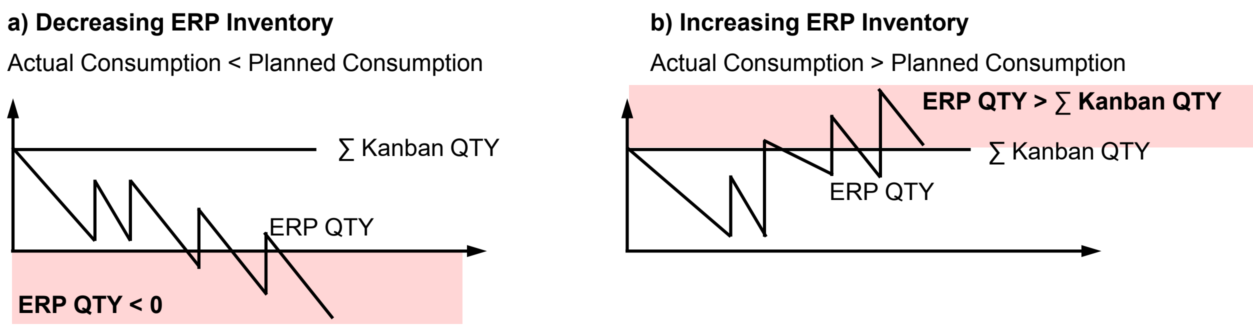

Figure 4: Detection of Inventory Deviations (Quantity)

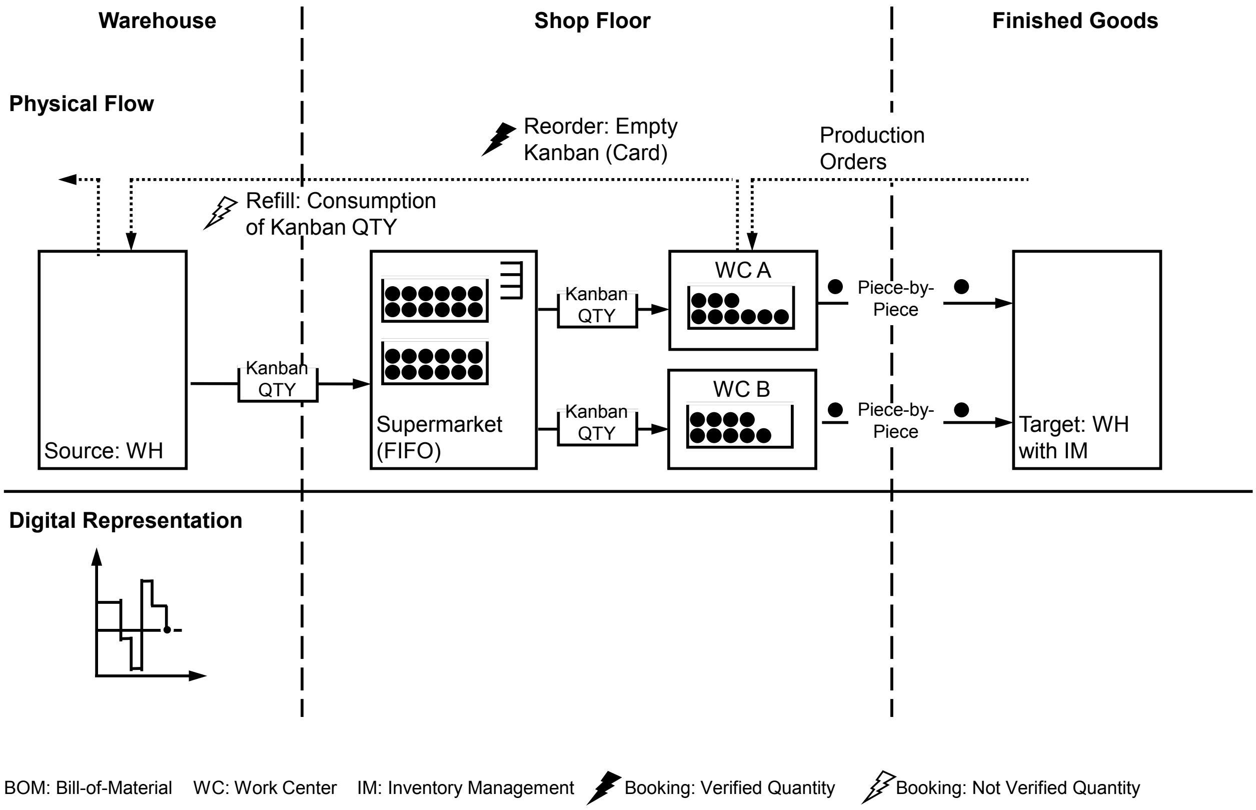

Figure 5: Classical Kanban (Physical shop floor Kanban)

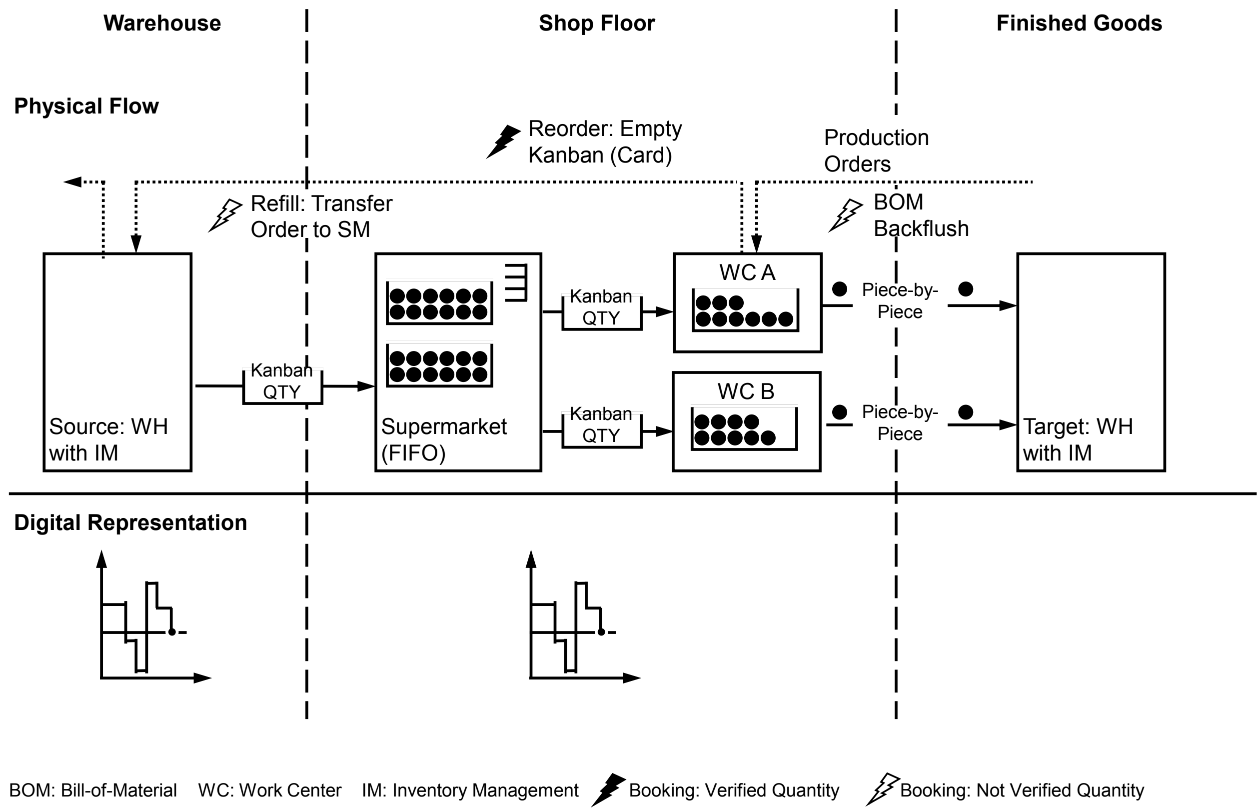

Figure 6: Robust Digital Kanban

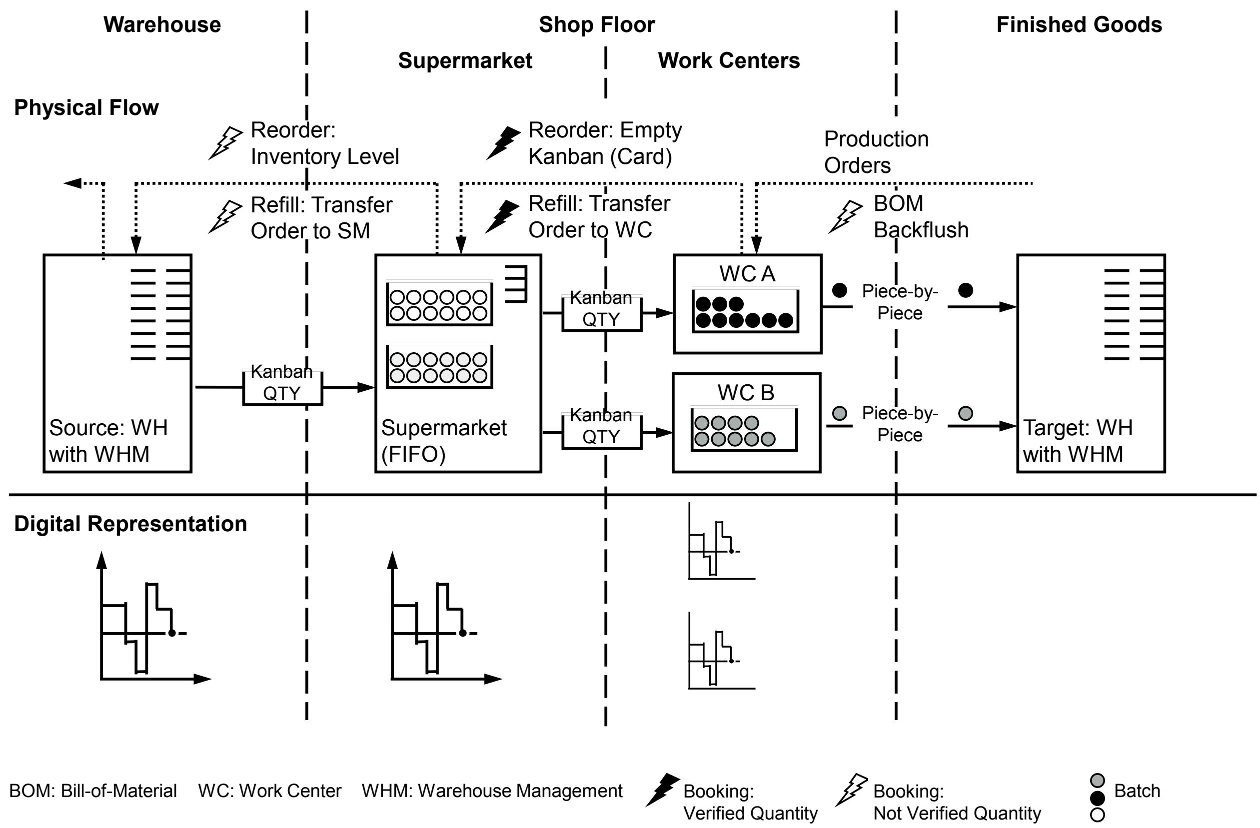

Figure 7: High resolution Kanban

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Biography

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