

Kanban-Based Three-Bin Replenishment System to Reduce Line Downtime and Material Shortages: A Case Study in a Leaf Vacuum and Generator Manufacturing Plant

¹ Sai Prasad Ravulapally

¹ Independent Researcher, Shakopee, Minnesota, USA

Received: 11th Jan 2026 | Received Revised Version: 12th Feb 2026 | Accepted: 12th Mar 2026 | Published: 27th Apr 2026

Volume 08 Issue 04 2026 | Crossref DOI: 10.37547/tajet/v8i4-327

Abstract

To maintain continuous production in high-volume manufacturing settings, the implementation of efficient internal logistics and material replenishment systems is essential. This study offers a case analysis of the design and implementation of a Kanban-based three-bin replenishment system within a manufacturing facility that produces leaf vacuum equipment and portable generators. The plant's previous operational framework, characterized by a push-based material delivery system, was plagued by considerable operational shortcomings. These deficiencies manifested as frequent material shortages, excessive inventory accumulation on the production line, and insufficient visibility into material status. Examination of ERP data indicated that material shortages were responsible for roughly 56 hours of monthly production downtime. Moreover, the existence of obsolete or compromised inventory contributed to annual scrap costs nearing \$240,000.

To address these challenges, a three-bin Kanban pull system was implemented. This system included standardized containers, separate storage areas for warehousing and production, visual labeling, and a pre-defined tugger delivery route linking a central warehouse with ten production lines. An evaluation was conducted, utilizing six months of baseline operational data and a two-month pilot implementation across four assembly lines.

The numbers indicate significant operational gains. The average monthly downtime attributed to materials saw a dramatic reduction, plummeting from 56 hours to 4 hours.

In the worst cases, it took operators more than two hours to find parts. Now it only takes about two minutes. Inventory waste plummeted by nearly 80%, slashing yearly scrap expenses from roughly \$240,000 to around \$48,000. These outcomes clearly demonstrate that reworking internal logistics using Kanban-inspired container systems can significantly boost material availability, production dependability, and operational efficiency within high-volume assembly environments.

Keywords: Kanban, Lean manufacturing, Pull systems, Inventory management, Internal logistics, Production downtime, Three-bin replenishment, Push systems.

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Cite This Article: Ravulapally, S. P. (2026). Kanban-Based Three-Bin Replenishment System to Reduce Line Downtime and Material Shortages: A Case Study in a Leaf Vacuum and Generator Manufacturing Plant. *The American Journal of Engineering and Technology*, 8(4), 141–147. <https://doi.org/10.37547/tajet/v8i4-327>.

1. Introduction

Maintaining a steady flow of production in today's manufacturing environments hinges on reliable material

sourcing systems. Even minor disruptions in material supply can lead to significant productivity setbacks and

operational inefficiencies, especially in high-volume assembly lines. Despite the advantages of more modern approaches, many manufacturing firms continue to rely on outdated, push-based replenishment strategies. These methods depend on historical demand data or forecasts, rather than the immediate signals generated by current consumption.

Push-based material systems often result in excessive inventory levels while still failing to prevent stockouts. When materials are delivered based on predicted demand instead of actual usage, organizations frequently experience mismatches between supply and production requirements. These mismatches may lead to production delays, urgent expediting, and inefficient labor utilization. The idea behind lean manufacturing is to get rid of waste and make sure that production systems always have a steady flow (Womack & Jones, 2003). The idea of pull-based replenishment is an important part of lean systems. In this system, moving materials is triggered by consumption at the downstream process.

People use kanban systems a lot to put pull-based material control into action. Originally created as part of the Toyota Production System, Kanban uses visual signals to give the go-ahead for the movement or production of materials based on how much is actually used (Ohno, 1988). Kanban also helps keep track of work-in-progress inventory by limiting the number of containers that can move through the system.

This study investigates the deployment of a Kanban-based three-bin replenishment system in a manufacturing facility that produces leaf vacuum and generator equipment. The plant has ten assembly lines and takes care of about 180,000 stock keeping units (SKUs), including 18,000 small components stored in bins.

Before the improvement project, the production lines often had to stop production because materials were missing. Operators also wasted a lot of time looking for parts because the storage areas were not well organized. The plant also lost a lot of inventory because it stored old or contaminated parts near production lines.

The goal of this study is to explain how a three-bin Kanban system was designed and put into use, as well as to look at how it affected production downtime, operator search time, and inventory waste.

2. Literature Review

2.1 Lean Manufacturing and Just-in-Time Systems

The Toyota Production System gave rise to lean manufacturing principles, which stress getting rid of waste,

always getting better, and moving materials around quickly (Liker, 2004). One of the main goals of lean manufacturing is to cut down on activities that don't add value during the production process.

Just-in-Time (JIT) production is a key part of lean manufacturing. Its goal is to make and deliver materials only when they are needed and in the exact amount needed (Monden, 2012). JIT systems lower the amount of stock on hand and make it easier to respond to customer requests. But for JIT to work, the processes for getting materials back in stock must be very reliable.

2.2 Kanban Systems

Kanban systems serve as visual communication mechanisms that regulate production and material movement in pull-based manufacturing environments (Sugimori et al., 1977). In a Kanban system, each card or container gives permission to move or make a certain amount of material.

When a downstream operation empties a container, the Kanban signal tells the upstream process to fill it up again. This technique makes sure that production is closely related to actual use.

In assembly settings where tiny parts are utilized a lot, container-based Kanban systems are often employed. Standardizing the sizes and amounts of containers may help businesses keep track of their inventory more easily while also making sure that materials are always available.

2.3 Multi-Bin Replenishment Systems

Two-bin systems are one of the easiest ways to set up a Kanban. This method keeps two containers for each part number. When the first container is empty, it is sent to be refilled while people keep using the second container. But situations with longer lead periods for replenishment or more variable demand may need more buffer capacity. Three-bin systems build on the two-bin idea by adding a third bin that usually stays at the warehouse or supplier's location.

The third container adds more coverage and lowers the chance of running out of supply while keeping the signals simple.

2.4 Kanban in Internal Logistics

Kanban systems are also commonly utilized for internal logistics and restocking from the warehouse to the line, in addition to scheduling production. Studies have shown that Kanban-based replenishment systems may markedly decrease inventory levels, augment material visibility, and

elevate operational efficiency (Hopp & Spearman, 2011). However, there is a paucity of research that records extensive Kanban deployments, including thousands of SKUs and several production lines. This research enhances the literature by offering a comprehensive case study of a plant-wide three-bin Kanban deployment.

3. Case Description: Company X and Baseline System

3.1 Plant and product overview

The plant runs 10 assembly lines, each building different models. Approximately 12 operators work on each line during a single daily shift, and total plant output averages about 135,600 units per month.

A central warehouse serves all lines. Overall, the plant manages roughly 180,000 SKUs, including components, fasteners, and subassemblies. Approximately 18,600 small-part SKUs are handled in bins and are the focus of the Kanban project.

3.2 Baseline push-based material handling

Under the baseline process:

- Buyers placed orders based on demand knowledge and historical data.
- Materials arrived at receiving and were then moved into the warehouse.
- Material handlers stored incoming items wherever space was available, without fixed locations per SKU.
- A bin team later pulled materials from various locations to a binning area and filled bins.
- Tugger drivers transported bins from the binning area to lines on a push basis, placing them on line-side flow racks regardless of immediate demand.
- Empty bins were collected and returned to the binning area, but did not act as a formal replenishment signal.

Lines requested additional materials by phone or radio when shortages occurred. This created reactive, urgent deliveries and contributed to high variability in material flow.

3.3 Baseline performance and issues

The push-based system led to several problems:

- **Downtime and shortages.** Over six months, material-related downtime averaged 56 hours per month across all lines. Eight lines reported recurring stops due to missing parts; only two lower-demand lines were less

affected. About 65 shortage incidents per month were recorded.

- **Searching and motion.** Because warehouse locations were not dedicated and line-side storage was cluttered, operators and material handlers spent large amounts of time searching for parts. Time studies found that in typical problematic cases, locating a needed part could take around 2 hours 32 minutes per part per person.
- **Inventory waste.** ERP data indicated roughly 240,000 USD per year in scrapped or written-off bin-managed inventory due to excess ordering, obsolescence, or dust contamination from long-term storage at the line.
- **Congestion and safety.** Excess bins at line-side created congestion and made access and picking more difficult, with ergonomic and safety implications.
- **Poor visibility.** Without standard locations or clear signals, it was hard to see which parts were low, misplaced, or obsolete. Auditing and problem-solving were slow.

Value stream mapping and spaghetti diagrams underscored the complexity of material flow. Material handlers often traversed about 160 meters per trip, with frequent backtracking between receiving, random rack locations, the binning area, and lines.

4. Methodology

4.1 Research design

The project followed a practical improvement initiative structured as a case-based before-and-after study. The intervention was a three-bin Kanban replenishment system for approximately 18,600 bin-managed SKUs. The phases were:

- **Baseline:** six months of data under the push system.
- **Pilot:** two-month implementation on four assembly lines.
- **Rollout:** extension to all 10 lines, followed by post-implementation measurement.

This structure allowed learning and adjustment during the pilot before full deployment.

4.2 Data collection

Data were collected from:

- **ERP and production systems:** line downtime attributed to material shortages, count of shortage incidents, scrap, and write-off costs.

- **Time studies and observation:** operator and handler searching times, material flow patterns, and travel distances.
- **Layout and flow analysis:** high-level layouts, value stream maps, and spaghetti diagrams to support route design.
- **Project documentation:** implementation plans, standard work, and feedback from operators and supervisors.

4.3 Measures

Key outcome measures were:

- **Material-related downtime (hours/month):** total monthly hours when any line was stopped due to missing material. Baseline average: 56 hours; post-implementation target/observed: about 4 hours.
- **Operator searching time (minutes per part):** time needed to locate and retrieve a specific part. Baseline: around 2 hours 32 minutes in typical difficult cases; post-implementation: approximately 2 minutes.
- **Inventory-related waste cost (USD/year):** annual scrap and write-off cost for bin-managed SKUs. Baseline: 240,000 USD; post-implementation: about 80% lower (roughly 48,000 USD), implying savings around 192,000 USD.

4.4 Constraints and assumptions

The project operated under limited IT and budget resources. The plant used existing ERP and warehouse systems, with manual and visual Kanban rather than electronic systems. Safety and ergonomics had to be maintained when changing bin sizes, rack configurations, and routes. Demand showed some fluctuation, and key suppliers had four- to six-week lead times; min–max settings were sized to accommodate this. It is assumed that no major unrelated process changes significantly altered the studied metrics during the evaluation.

5. Kanban-Based Three-Bin System Design

5.1 Design principles

The three-bin system followed these principles:

- Pull from actual consumption at the line.
- Standardize four bin sizes based on SKU dimensions, weight, and demand.
- Assign fixed warehouse and line-side locations for each bin SKU.

- Use bins with permanent labels as the Kanban signal instead of separate cards.
- Define and standardize tugger routes and frequencies.

5.2 Process flow

The new process has two linked flows: procurement/put away and internal replenishment.

5.2.1 Procurement and put away

Each bin SKU received min–max levels based on demand and four- to six-week supplier lead times. When warehouse stock for a SKU reached its minimum, buyers ordered a standard quantity to restore stock to the maximum. Upon arrival:

- Materials were received and checked.
- Material handlers placed items in their dedicated warehouse rack locations, aligned with the chosen bin size.

5.2.2 Internal replenishment with three bins

For each bin SKU, three bins were used:

- **Bin 1:** in use at the line.
- **Bin 2:** full and ready as backup at the line or warehouse.
- **Bin 3:** circulating between warehouse and receiving or acting as buffer.

The cycle:

1. Operators consume from Bin 1, stored on a line-side flow rack.
2. When Bin 1 is empty, the operator moves Bin 2 into use and places the empty Bin 1 on a top rack reserved for empties.
3. Tugger drivers run a fixed route at defined intervals, collecting empty bins from all lines and transporting them to a dedicated empty-bin area in the warehouse.
4. In the warehouse, pickers sort empty bins by zone. Each bin's label indicates SKU, standard quantity, warehouse location, line, rack position, and bin number.
5. Pickers refill bins from dedicated locations and stage them on tugger carts organized by line and aisle.
6. Tugger drivers deliver refilled bins on the same standardized route, placing them in their exact line-side positions and collecting any additional empties.
7. Bin 3 ensures that one bin is in use, one is ready, and one is being replenished or in transit.

Route frequency is set so that the time from collecting an empty bin to returning its refilled bin is less than the time required to consume the backup bin.

5.3 Labeling and visual control

A key design choice was to abandon separate Kanban cards after early pilots revealed card loss. Instead, each bin is permanently dedicated to a specific SKU and labeled with:

- SKU number and standard bin quantity.
- Warehouse location.
- Production line and supermarket rack location.
- Bin number (1, 2, or 3).

The bin itself is the Kanban signal. The presence of an empty bin on the top rack signals replenishment; the presence or absence of bins at known locations serves as a visual indicator of status. Standardized roller flow racks with fixed positions for each SKU further support visual management and audits.

5.4 Parameter setting and route design

To set bin sizes and min–max levels, SKUs were grouped by demand and physical characteristics. Each group was assigned one of the four bin sizes and bin quantities consistent with consumption between trolley cycles, plus safety.

Spaghetti diagrams of baseline routes informed a new trolley route that minimized distance and backtracking while visiting all lines in a predictable loop. Route frequency was chosen to match consumption patterns and avoid both stockouts and excessive material accumulation.

6. Results

6.1 Pilot on four lines

The three-bin system was piloted on four lines for two months. On these lines, material-related downtime decreased from levels consistent with the plant-wide baseline to about 25 hours per month. Operators reported fewer urgent calls to the warehouse and less waiting for parts. Line-side organization improved as bins were stored only in designated positions, and the pilot exposed card-loss issues that were resolved by switching to labeled bins as signals.

6.2 Plant-wide performance

After adjustments from the pilot, the three-bin system was rolled out to all 10 lines and 18,600 bin-managed SKUs. Post-implementation data showed:

- **Downtime:** average monthly material-related downtime dropped from about 56 hours to roughly 4 hours. Remaining downtime was mainly due to unusual events (e.g., external supply disruptions) rather than everyday internal issues.
- **Shortage incidents:** the number of shortage incidents per month fell sharply from about 65 to 0, reflecting improved reliability of material supply.
- **Searching time:** operator and handler searching time for parts decreased from around 2 hours 32 minutes per part per person in problematic cases to about 2 minutes, which is due to fixed bin locations and clear labels.
- **Inventory-related waste:** annual scrap and write-off costs for bin-managed SKUs dropped by about 80%, from roughly 240,000 USD to around 48,000 USD, implying savings of approximately 192,000 USD.
- **Line-side inventory and space:** line-side inventory for bin-managed SKUs was reduced as the number of bins per SKU was fixed and excess storage was eliminated, freeing space and improving ergonomics.

7. Discussion

The case shows that a carefully designed three-bin Kanban system can substantially improve material availability and reduce waste in a high-volume assembly environment. By linking replenishment directly to bin empties at the line, the plant moved from reactive, push-based deliveries to a predictable pull flow.

The sharp reduction in material-related downtime suggests that many baseline stoppages were caused by internal process variability and lack of synchronization rather than inherent external volatility. Standardized bins and dedicated locations improved 5S, reduced searching, and made material status visible at a glance. The move from Kanban cards to labeled bins removed a common failure mode in manual Kanban systems.

From a financial perspective, approximately 80% reduction in inventory-related waste demonstrates that Kanban-based control of bin-managed SKUs can significantly reduce scrap and obsolescence, especially when parts were previously overordered and stored for long periods at the line. Lower searching time also freed operator and handler capacity for value-adding work.

Practically, the project underscores that:

- Replenishment design should start at the line, with clear supermarket concepts and consumption logic.
- Standardizing bins, racks, and labels is critical when thousands of SKUs are in scope.
- Simple, visual, container-based signals can be more robust than separate cards when discipline is maintained.
- Route design and frequency must be consistent with bin sizing and demand.

Change management was an important factor. Operators and material handlers needed training to trust and follow the new system instead of calling the warehouse whenever they felt uncertain. Early problems with cards had to be addressed quickly to preserve confidence. Maintaining progress demands ongoing audits, refresher training sessions, and a consistent emphasis on standard work practices.

The study is subject to certain limitations. It focuses on a single plant, and some of the data comes from time studies and educated guesses, rather than constant, detailed measurements. While other factors may have influenced performance during the study, no major confounding variables were found. Despite these limitations, the size and consistency of the observed improvements suggest that the three-bin system was the main cause.

8. Conclusions and Future Work

This paper describes the implementation of a Kanban-based three-bin replenishment system at a manufacturer of leaf vacuums and generators. The baseline push system led to frequent material shortages, long searching times, excess line-side inventory, and about 240,000 USD per year in inventory-related waste. A three-bin pull system with standardized bins, fixed locations, labeled containers, and structured tigger routes reduced average monthly material-related downtime from about 56 to around 4 hours, cut searching time to minutes, and lowered inventory-related waste by roughly 80%.

This case study suggests that improving internal logistics and replenishment design can significantly boost operational performance and reduce costs in assembly environments with high production volumes. The design principles and steps described here are applicable to other plants with similar characteristics when considering Kanban-based bin systems.

Future research could explore electronic Kanban systems or sensor-equipped bins to improve visibility and data gathering. It could also involve replicating the

methodology across various plants or sectors and employing simulation or optimization models to fine-tune bin dimensions and routing schedules. Combining three-bin Kanban systems with other warehouse practices, such as dynamic slotting, may also yield additional benefits.

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