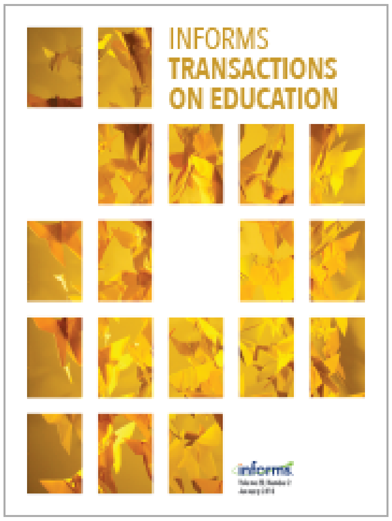

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Case

Forward-Reserve Storage Design: A Case of Carriage Repair Workshop, Indian Railways

Vishwesh Singbal,[a] Gajendra K. Adil,[a] Rakesh Venkitasubramony[b]

[a] Shailesh J. Mehta School of Management, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India; [b] Indian Institute of Management Lucknow, Prabandh Nagar, Lucknow 226013, India

Contact: vishwesh.singbal@iitb.ac.in, https://orcid.org/0000-0002-5273-3818 (VS); adil@iitb.ac.in, https://orcid.org/0000-0002-8412-8268 (GKA); rakesh.v@iiml.ac.in, https://orcid.org/0000-0002-8699-3765 (RV)

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1. Introduction

Mr. Joe, the materials manager of the carriage repair workshop of Indian Railways in a suburb of Mumbai, sounded worried.

> We fought hard to obtain sanction for this AS/RS (automated storage/retrieval system) to modernize our operations and reduce our dependence on manual labour. However, now that it is here, we are grappling with issues we had not anticipated. We believe these are only teething problems.

He was briefing Ravi, a young academician from a leading university, whom he had invited to help him deal with an unusual problem. (The characters in this scenario are fictional.) A veteran of Indian Railways, Mr. Joe had headed many projects and dealt with many problematic situations over the years but found himself to the end of his wits in this one. "Surely the equipment is working the way it was promised to us. But the rate at which storage and retrieval operations are completed is much slower than it was when we had manual warehousing," he continued. "We cannot change the racks to have a manual interface, as it will take more time and expenditure. You must find a way to help us without having to make any structural changes or involving extra manpower," he insisted. This situation presented an exciting opportunity for Ravi to use his knowledge to solve a practical problem.

2. Company Background

Indian Railways is an undertaking of the government of India and is overseen by the ministry of railways. It runs the world's third-largest rail network. It enjoys a monopoly over all rail transportation in India and transports more than 23 million passengers daily in more than 12,600 passenger trains. Additionally, it transports more than 1 billion tonnes of cargo annually. The major growth drivers for Indian Railways have been increasing urbanization, rising incomes, rising investment, and participation by the private sector.

In a bid to meet the huge demand for passenger and cargo transportation, Indian Railways uses more than 9,000 locomotives (diesel and electric), 63,000 coaches, and 2,40,000 wagons. To prevent breakdowns and accomplish quick repairs, the company has set up workshops at various locations across the country. One such workshop was set up in Mumbai for carrying out repair, maintenance, and overhauling activities. Different types of spares (1,000+ types) in various quantities were required for these activities. The spares were stored onsite in a warehouse. In recent years, Indian Railways had adopted a modernization strategy by focusing on key areas such as core assets, revenue models, projects, and resources. Their modernization strategy also included using available technology to improve their functioning at their existing manufacturing and repair facilities.

3. Configuration and Operation of the AS/RS

Automation in warehousing has brought in many advantages such as better accuracy, better safety, higher throughput, and higher space utilization. Warehousing systems have evolved vastly since the introduction of automated storage/retrieval system (AS/RS) in the 1950s. Indian Railways installed an AS/RS at the carriage repair workshop in 2018, which centrally held more than 60% of SKUs (stock keeping units) of spare parts. Indian Railways opted for a multiaisle AS/RS with a single storage/retrieval (S/R) machine serving all the aisles. This type of system was suitable for the low throughput and high storage requirement at the workshop. Also, multiaisle AS/RS offered a significant cost advantage over conventional AS/RS with aisle-captive S/R machines because it is estimated that nearly 40% of the total expenditure is required for purchase of S/R machines in a conventional AS/RS. Additionally, multiaisle AS/RS are more amenable for expansion.

Figure 1 shows the schematic of this AS/RS. The AS/RS has eight parallel picking aisles, each having a single-deep storage rack on either side. Each storage rack has 192 storage slots (16 storage slots along the picking aisle and 12 storage slots along the height). A single S/R machine carries out all the storage and retrieval activities. The S/R machine consists of a crane with a hoisted carriage. It allows simultaneous horizontal (along the X direction at a speed of 1.6 m/s) and vertical (along the Y direction at a speed of 0.6 m/s) motions of the crane and hoisted carriage, respectively, when in the picking aisles. The S/R machine is moved from one aisle to another using a transfer car. The transfer car can move only along the Z axis with a speed of 0.3 m/s. The pick-up/drop-off (P/D) point for the S/R machine is located at the start of the cross-aisle.

The spares required by the workshop are received in loose form in small gunny bags. These are stored in steel cages (Figure 2), which are handled by the S/R machine as a unit load. The carriage on the S/R machine can hold one cage at a time. Each storage slot can hold one cage (i.e., one unit load).

Putaway is the operation in which the cage containing spare parts is moved from the P/D point to an appropriate storage slot for storage. Likewise, the retrieval operation of a product is called a *pick*. The sequence of motions for putaway and pick operations is given in Table 1.

As observed from Table 1, for every pick operation, there are two round trips between the P/D point and the target storage slot (compared with one round trip required for the putaway operation). The first trip is to pick the cage containing the required product and follows a similar sequence of motions and activities like that for the putaway operation with the main difference being the interchange of cage loading and unloading activities. The second trip is required to putaway the retrieved cage back to its storage location and involves the exact same sequence of motions and activities as a putaway operation. The P/D point serves as a dwell point for the S/R machine. This means that each putaway or pick operation starts and terminates at the P/D point.

Every round trip of the S/R machine from the P/D point to a storage location and back involves one each of cage loading and unloading activities, two each of attaching and detaching of the S/R machine and the transfer car, two travels of the transfer car carrying the S/R machine between the P/D point and destination picking aisle, and two travels of the S/R machine between the entrance of the picking aisle and target storage slot. It may be noted that each of these activities/motions contributes toward the total request (storage or retrieval) completion time. Although the times spent for loading/unloading a cage in/from S/R machine and for attaching/detaching of the S/R machine and transfer car are constants, the travel times of the transfer car (in the cross-aisle) and S/R machine (in the picking aisle) depend on where the products are placed in the warehouse. Thus, any significant reduction

Figure 1. Schematic Layout of AS/RS (Not to Scale)

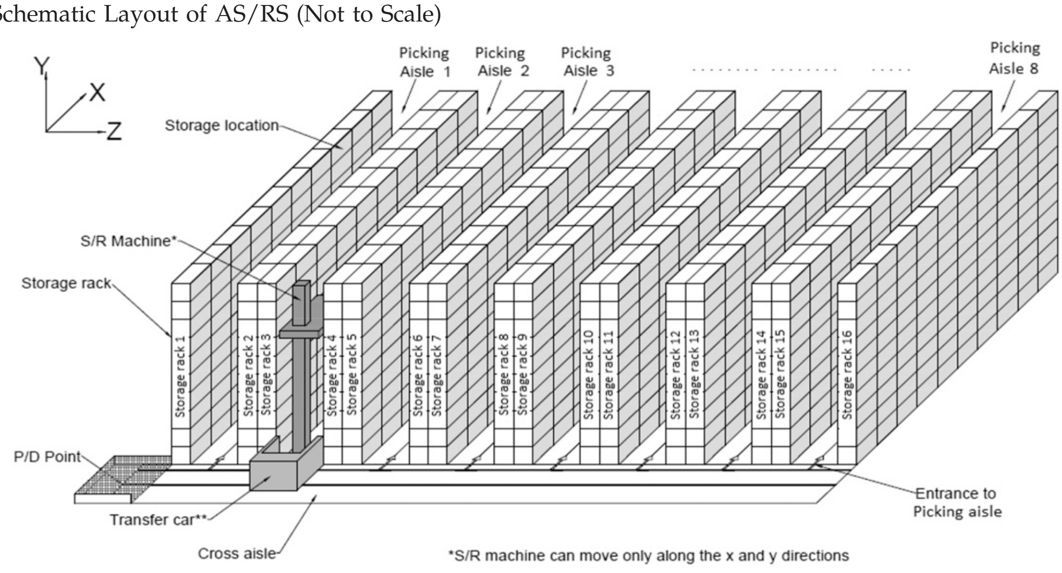
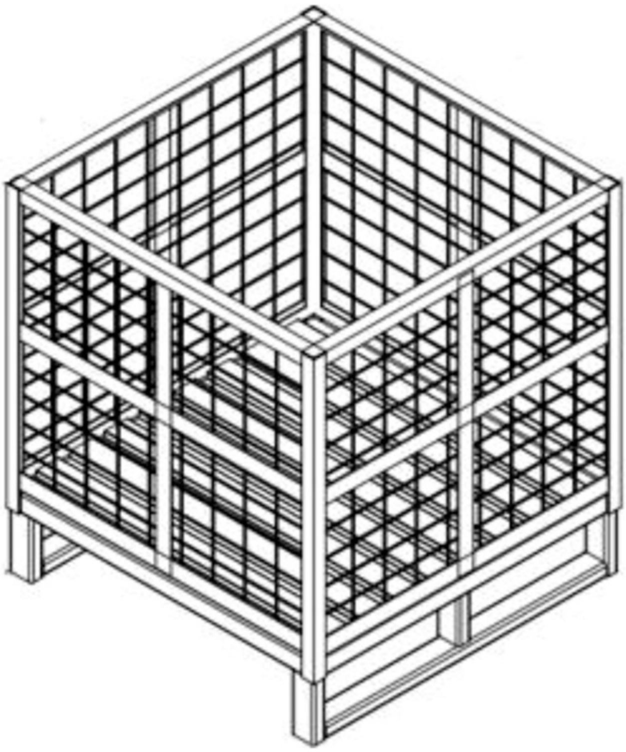


Figure 2. Cage Used for the Storage of Loose Spares in the AS/RS



in the request completion time is possible through the reduction of respective travel times of the transfer car and S/R machine.

4. Problems Faced

The AS/RS brought with it several benefits such as increased accuracy, better safety, higher space utilization, and higher storage density. However, in a manual system, even when a shortage of manpower was faced, the work did not come to a standstill; however, this would happen in the AS/RS if the single crane required repair or broke down. Because the storage racks are accessible only to the S/R machine, no manual storage or retrieval is possible if the S/R machine is not operational. Furthermore, meeting the throughput requirement is extremely important for the workshop, as Mr. Joe remarked.

> Having a single crane does save us a huge amount of capital investment. However, it must be able to serve all the product requests received by the warehouse. Delayed servicing of requests is leading to holding up the repair and maintenance of the jobs. This could be catastrophic for the whole facility.

Ravi gathered all the information that he would need to come up with a solution to this peculiar problem. Because Mr. Joe clarified that structural changes were not possible, he decided to examine how the products were distributed to different aisles and assigned storage slots in the storage racks.

Currently, products are distributed to different racks so that each rack gets the same number of pick/putaway requests. This type of product distribution is called *interleaved balanced load distribution*. Under this distribution, the expected one-way travel time of the transfer car in the cross-aisle remained the same regardless of how the products are assigned storage slots within a storage rack. Ravi decided that he would continue with interleaved balanced load distribution because it allowed storage of the same product across multiple aisles, thereby ensuring product availability in case a particular aisle is inaccessible.

As per the prevailing practice, the products were stored randomly within a rack. The within-rack expected one-way travel time per request under random storage policy was found to be 11.54 seconds.

Table 1. Sequence of Motions in Putaway and Pick Operations

Putaway operation	Pick operation
1. S/R machine at the P/D point loads the cage to be stored in its carriage.	1. Empty S/R machine at the P/D point gets attached to the transfer car.
2. Loaded S/R machine gets attached to the transfer car.	2. The transfer car transports the S/R machine to the entrance of the destination picking aisle.
3. The transfer car transports the S/R machine to the entrance of the destination picking aisle.	3. S/R machine detaches from the transfer car.
4. S/R machine detaches from the transfer car.	4. S/R machine travels to the target storage slot in the picking aisle.
5. S/R machine travels to the target storage slot in the picking aisle.	5. The requested cage is picked from the target storage slot into the carriage of the S/R machine.
6. The cage loaded on the S/R machine is placed in the target storage slot.	6. Loaded S/R machine returns to the entrance of the picking aisle.
7. Empty S/R machine returns to the entrance of the picking aisle.	7. S/R machine gets attached to the transfer car.
8. S/R machine gets attached to the transfer car.	8. The transfer car transports the S/R machine to the P/D point.
9. The transfer car transports the S/R machine to the P/D point.	9. S/R machine detaches from the transfer car at the P/D point.
10. S/R machine detaches from the transfer car at the P/D point.	10. S/R machine unloads the cage in its carriage at the P/D point.
	11. At the P/D point, the required quantity of material is withdrawn and the cage is then putaway to its storage slot.

Thus, there is an opportunity for reducing travel time by focusing on how the products are assigned storage locations within a storage rack.

Ravi considered the product composition of one rack and decided to figure out ways to reduce the expected travel time for that rack. The rack under consideration housed SKUs of 63 products. All the past data regarding the number of picks and replenishments for these products were provided to him by Mr. Joe. Ravi calculated the total storage space that would be required under a dedicated storage policy, which would ensure some reduction in travel time compared with that under the random storage policy. To his dismay, he found that the total storage space required would be 312 cages or storage slots. This far exceeded the storage capacity of the storage rack at 192 storage slots. This ruled out the use of a dedicated storage policy. On the other hand, under a random storage policy, the storage requirement was found to be only 154 storage cages. This allowed buffer storage of 38 storage slots. Ravi needed to think of a way to combine the storage efficiency of the random storage policy and the picking efficiency of the dedicated storage policy. He knew of one storage mechanism that achieved this: forward-reserve storage configuration. Ravi had studied this storage mechanism only in the context of manual warehousing and wondered whether its application could be extended to AS/RS. He decided to give it a try.

5. Forward-Reserve Configuration

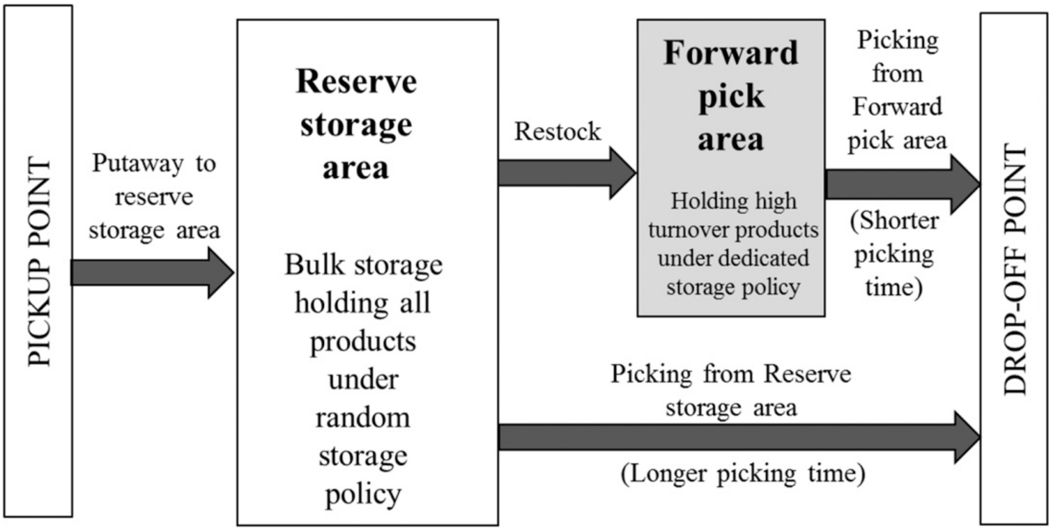
For any storage facility, the major objectives are efficient storage (high space utilization) and efficient order picking (low picking time). These objectives may not go together because each objective is achieved under a different storage policy. However, a forward-reserve configuration is one storage arrangement that combines these objectives. Under this configuration, the warehouse has a *forward pick area* and a *reserve storage area* as shown in Figure 3.

Typically, the forward pick area is the one that offers convenience for picking. This area is located close to the dropoff point of the warehouse, thereby reducing the travel time in picking a product stored in this area. The storage policy followed in a forward pick area is a dedicated turnover-based storage policy ensuring that high turnover products are placed closer to the dropoff point. The size of the forward pick area is kept small to preserve this picking efficiency. The reserve storage area is much larger compared with the forward pick area. All the incoming material in the warehouse is first stored in the reserve area. The storage policy in force in the reserve area is a random storage policy ensuring high space utilization.

Products that do not have any SKU in the forward pick area are picked directly from the reserve area. Products that are stored in the forward pick area are picked only from the forward pick area. These are regularly restocked from the reserve area as shown in Figure 3. Thus, the actual tradeoff in a forward-reserve storage configuration is between the gain in faster picking of high turnover products from the forward pick area and the additional time spent in restocking the products in the forward pick area from the reserve area.

When adapting the forward-reserve configuration for the storage rack considered from the AS/RS, it must be noted that the pickup point and dropoff point for evaluating picking efficiency are the same (i.e., the aisle entrance point).

Figure 3. Logical Representation of Material Flows in a Forward-Reserve Storage Arrangement



Ravi wondered if the concepts he had learned about forward-reserve configuration in the context of manual warehousing can be applied to the problem at hand to help Indian Railways meet the throughput requirement. The major decisions in implementing the forward-reserve configuration for the AS/RS are as follows.

5.1. The Size of the Forward Pick Area

In order to achieve picking efficiency, it was desirable to accommodate a significant portion of high-turnover products in the forward pick area. However, as the size of the forward pick area increased, the additional reduction in pick distance became incremental, and the buffer space available in the rack decreased, which needs to be taken into account. In view of this tradeoff, one must determine the optimum size of the forward pick area.

5.2. Selection of SKUs and Their Location Assignment to the Forward Pick Area

Ravi needed to ensure that the right products were selected for storage in the forward pick area and were assigned to the most appropriate storage locations so that the overall benefit in implementing forward-reserve storage is maximized.

5.2.1. Ranking the Storage Slots. Unarguably, the forward pick area comprises the premium slots from the order picking perspective. However, each slot in the forward pick area does not offer the same picking benefit. Therefore, the storage slots in the forward pick area were to be ranked in the increasing order of the time taken to reach it from the aisle entrance. Any tie would be broken by ranking the one with lower replenishment time from the reserve storage area higher.

5.2.2. Heuristics for Selecting Products for the Forward Pick Area. Ranking the storage slots can help assign high turnover products to high-ranked storage slots. Ravi came up with some good rules of thumb or heuristics to achieve this objective.

Heuristic 1. A product that has a higher number of picks, if assigned to a premium storage slot, should result in shorter pick distances. Products can be ranked in the decreasing order of their number of picks as a rule of thumb. Then, a product with high rank can be assigned to a high-ranked storage location. For example, if product A has 100 picks and product B has 60 picks, then product A will be ranked higher than product B. Also, product A will be assigned higher-ranked slots than product B.

Heuristic 2. Ravi wished to consider a widely mentioned heuristic in warehousing research literature known as cube per order index (COI). Under this rule, a product is ranked higher if it has a higher turnover or if it requires less storage space. The products are ranked in the decreasing order of the ratio of the number of picks to the volume (total unit loads) of picks. Higher the ratio, the more preferred is the product for moving into the forward pick area. For example, consider a product A having 100 picks for a total of 10 unit loads. Consider another product B with 80 picks for a total of 4 unit loads. Then, product B will be ranked higher than product A because its picks-to-volume in unit loads ratio ($80/4 = 20$) is higher than that for product A ($100/10 = 10$).

5.3. Quantity of Each Selected SKU to Be Kept in the Forward Pick Area

The minimum number of storage slots required must be such that it ensures no stock out while waiting for restocking. For the products under consideration, based on the analysis of past picking patterns, Ravi concluded that one unit load of each product in the forward pick area is adequate to prevent stock-outs. Giving the product additional storage locations, beyond the minimum required, does not help in any way as it neither increases the number of picks from the forward pick area nor does it reduce the number of restocks. Therefore, it is suggested to have one unit load of each selected product in the forward pick area, with the balance quantity of that product to be stored in the reserve area. Furthermore, it is advisable to keep at least one unit load for each product in the reserve area so that new receipts can be stored without disturbing the forward pick area and FIFO (First In First Out) withdrawals are facilitated.

The overall benefit of the forward-reserve configuration can be assessed by comparing the total travel time in putaway, pick, and replenishment activities involved in this configuration with the total travel time under the currently practiced random storage. The replenishment activity requires an additional 30 seconds toward loading and unloading activities apart from travel time, which needs to be accounted for in this comparison. The two proposed heuristics do not explicitly consider these benefits in their entirety nor do they consider all possible product selection and location assignment options. Hence, an optimization model may be developed to help select products for storage in the forward pick area and to determine their location. Such an optimization model can consider an objective function to minimize the total travel time involved in putaway, pick, and replenishment

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activities for all the products in forward and reserve storage. It is possible to consider technological and modeling constraints such as a product being selected for picking from either the forward pick area or the reserve storage area but not both, and products can be assigned within the available slots in the forward pick area with a maximum of one slot per product type.

As Ravi looked at all the data he had gathered, he wondered whether he would come up with any useful solutions. The forward-reserve configuration surely looked promising, and the prospect of seeing it implemented was exciting. He, however, had to demonstrate a tangible benefit to convince Mr. Joe. With these thoughts, Ravi proceeded with his task.