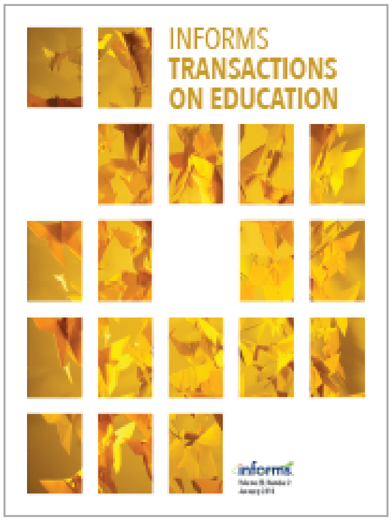

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Case Article

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

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Abstract. Case studies are useful in imparting decision-making skills to students. Warehousing is a critical part of most supply chains, but case studies based on warehousing methods and operations therein are rare. Recognizing the need to bridge this gap, a case study is designed to present a real-life scenario at the carriage repair workshop of Indian Railways. The case study facilitates the learning of students regarding operations in automated warehousing and relevant storage strategies. Additionally, the case encourages the students to explore the use of heuristics and optimization models. This case article highlights the major learning objectives of the case study and discusses the classroom teaching experience. This case can be used in various courses and the case questions can be selected based on the teaching objectives and/or the educational background of the students.

Supplemental Material: Supplemental materials are available at https://www.informs.org/Publications/Subscribe/Access-Restricted-Materials.

Keywords: automated warehousing • forward-reserve • heuristics • optimization

1. Introduction

Solving case studies often requires a nontraditional approach to problem solving and self-discovery by the students, which in turn results in better retention of concepts studied in classrooms (Parr and Smith 1998). In management courses, the use of case studies concisely depicting a management problem presents students with an opportunity to study the situation, come to their own conclusions regarding the solution, and defend their solution among their peers (Suresh 2002). Management science (MS) equips students with essential skills in basic quantitative reasoning, informal modeling, building and analyzing models on their own, and understanding and working with large-scale models (Powell 2001). However, teaching MS, particularly operations research (OR), to undergraduates and MBA students is not an easy task because the students may feel overwhelmed by the data analysis and modeling required (Vanhoucke 2010). Students without a strong mathematical background may find it difficult to formulate problems for OR techniques such as linear programming (Stevens and Palocsay 2004). Additionally, the gap between the content of the OR/MS course and the desire of students to learn practical skills may cause the students to lose interest in the course (O'Brien et al. 2011).

Vast improvements in computer software and hardware in the recent past leading to the development of several user-friendly tools has made it easier to solve problems using OR techniques (Alpers and Trotter 2009). Among these tools, spreadsheets are simple but powerful tools for use by academicians and practitioners because spreadsheets offer an adequate visual platform for model development (Liu et al. 2013). Spreadsheets find wide applications in different supply chain functions such as demand forecasting, resource optimization, and inventory management (Liu et al. 2013). Traditionally, material-handling research has found the application of OR useful in various areas such as robotics, conveyor theory, transfer lines, equipment selection, storage alternatives, automated storage/retrieval system (AS/RS), warehouse layout, and order picking (Matson and White 1982).

The use of case studies for teaching different areas of a supply chain (such as sourcing, materials management, operations planning, distribution, and logistics) is very effective. Warehouse management is a critical part of a supply chain as warehouses provide space for accumulation of goods (finished, intermediate, or raw materials) to meet uncertain demand. Over the years, warehousing has dramatically evolved through automation. However, case studies based on the setting of automated warehouse management are rare because most of the existing case studies discuss storage strategies in the context of a manual warehouse. This case study attempts to bridge this gap by presenting an interesting problem in warehousing at the carriage repair workshop of Indian Railways. This case study is developed keeping in mind that it may always not be feasible for students to have first-hand experience of different operations in an automated warehouse. Thus, the description of the AS/RS and the subsequent discussion of the problem scenario in the case study is intended to motivate students to take a greater interest in warehousing science. Research considering multiaisle AS/RS is sparse, and hence the use of this configuration in the case study also adds to the novelty factor of the case study. This case study is suitable for various master's level courses such as operations management, warehouse operations, industrial engineering, production management, logistics and distribution, and supply chain management. The case study can also be used in undergraduate management science, business administration, business analytics, and operations elective courses.

This case article is organized as follows. Section 2 discusses the advancements in automated warehouses and different storage strategies. Section 3 presents the case synopsis. Section 4 elaborates on the classroom experience of teaching this case study. Some concluding remarks are made at the end.

2. Automated Warehousing and Storage Strategies

The introduction of automation in warehouses (as in AS/RS) has reduced the cost of operations compared with manual warehousing (Roodbergen and Vis 2009). A multitude of configurations of an automated warehouse is possible because of different combinations of layouts, equipment, and operating policies (Roodbergen and Vis 2009). This makes warehouse design and operation very complex. One may refer to Roodbergen and Vis (2009) for a detailed literature survey of automated warehouses.

de Koster (2018) describes the different types of automated storage systems that have been developed since the introduction of simple AS/RS having aisle-captive storage/retrieval (S/R) machines. The automated systems have evolved technologically from using dedicated S/R machines to using autonomous vehicles, moveable racks, autonomous-guided vehicles, and robotic pickers. Other major advancements in warehousing are through the use of big data and analytics, the Internet of Things, a strategic workforce, mobile technology, advanced robotics, and new energy resources (Manci 2019). The increasing demand for faster delivery in e-commerce is unprecedented, and effective warehouse management is inevitable to achieve that (Boysen et al. 2018). The use of Kiva robots by Amazon.com, and the use of robots and waterways for material movement by Nike, Inc. are just two examples where warehousing automation plays a key strategic role (Maria 2019). However, the level of automation in warehousing has to be in line with the business requirement so that the high investment in adopting advanced technology is justified. The carriage repair workshop of the Indian Railways discussed in this case study has a high storage requirement relative to the throughput requirement. For this situation, an AS/RS where the number of S/R machines is fewer than the number of aisles is suitable (Lerher et al. 2010). This configuration is commonly known as multiaisle AS/RS (Hwang and Ko 1988). The AS/RS studied in the case has a single S/R machine that serves all the aisles. The movement of this S/R machine between the aisles is facilitated by the use of a transfer car (Rao et al. 1997).

In a warehouse, the storage policies determine where to place the incoming material. Storage policies are critical because the travel time of the S/R machine depends on where the product is stored in the AS/RS. This affects the order completion time because S/R machine travel time is its major component. Also, most researchers consider S/R machine travel time as a measure of warehouse performance. The major storage policies discussed in the literature are random and dedicated (Tompkins et al. 2015). Each of these two storage policies has its own advantages and drawbacks. Random storage policy offers a lower space requirement as the storage locations are shared among all the products. In contrast, under dedicated storage policy, the storage space requirement is usually higher than that under random storage policy because of earmarking of exclusive storage locations for each product. However, because product turnover is not taken into account when allocating storage locations to products in a random storage policy, average travel time in completing a request is usually higher than that under dedicated storage policy (Gu et al. 2010). Forward-reserve configuration is a storage arrangement that combines the storage efficiency of random storage policy with picking efficiency of dedicated storage policy (Bartholdi and Hackman 2008). To the best of our knowledge, this case study is the first of its type demonstrating the application of a forward-reserve configuration in a multiaisle AS/RS.

3. Case Synopsis

The case presents the warehousing problem at the carriage repair workshop of Indian Railways through the discussion between two characters (Mr. Joe, the materials manager, and Ravi, a young academic). The problem is regarding the throughput of a newly installed multiaisle AS/RS at the facility. The installed system has a single crane to service all eight of its aisles, which has raised concerns regarding the throughput capacity of the system. The prevailing storage policy at the warehouse is a random storage policy. Implementation of a turnover-based dedicated storage policy that will reduce travel time (resulting in increased throughput capacity of the system) is not feasible because of limited storage space. Mr. Joe wants Ravi to explore options for increasing the throughput without any changes to the structure of the AS/RS or any additional investment. Ravi wonders whether the concept of forward-reserve configuration can be applied to this scenario. The forward-reserve mechanism is expected to balance picking efficiency and space utilization. As followed in a manual warehouse, in a forward-reserve configuration for the AS/RS, a small area near the picking aisle entrance would be used for the storage of fast-moving items with turnover-based item placement. This would lead to the concentration of trips of the S/R machine in that area, resulting in reduced picking time. The rest of the storage space in the rack would be a reserve area that uses random storage for better space utilization.

3.1. Learning Objectives

The major learning objectives of this case are as follows:

- Introducing the students to AS/RS and discuss the various operations that are carried out in it.
- Understanding the impact of storage policies (such as turnover based dedicated storage policy and random storage policy) on space requirement and response time.
- Understanding and applying the forward-reserve configuration concept to the AS/RS.
- Understanding the use of heuristics in a real-life scenario such as storage system design.
- Providing the students with an opportunity to formulate a linear programming problem for product selection and space allocation in the forward-reserve configuration. The students are encouraged to use software tools (MS Excel Solver, OpenSolver plugin for MS Excel, etc.) to solve it.

3.2. Supplementary Material

The following supplementary material is provided with restricted access.[1]

- Technical note: This document details the turnover-based dedicated and random storage policies. It also discusses the economics of a forward-reserve configuration in AS/RS.
- Case data (MS Excel file): The notations used in the case data excel sheet are as per part B of the technical note.
- The teaching note along with the solution to assignment questions in MS Excel: The teaching note consists of four questions prescribed for this case. The solutions for these questions along with some other information are discussed in the teaching note.

4. Classroom Experience

For testing how well the case study succeeded in meeting its learning objectives, this case study was prescribed as a class assignment in two different courses in the Master of Management program. The two courses were the first-year course Operations Management (OM) and the second-year elective course Warehouse Operations (WO). In this section, the response of the students in the OM course is discussed first, followed by that in WO.

The number of students in the first-year OM class was 120. The students primarily had an engineering educational background. There were a few students with other educational backgrounds, such as humanities and business management. Many of the students were not familiar with warehousing and the operations therein. Thus, an introductory session was conducted for the students that covered an introduction to warehousing and storage policies. The content for this session was drawn from the supplemental material (technical note). The students were then grouped into teams, with each team having not more than five members. Knowledge of linear programming is required for solving a question in the case study. However, there was no requirement of any introductory session covering linear programming techniques because the students were familiar with it. The students were allowed a duration of one week to solve the case study questions.

The preparatory class proved fruitful in helping students in the OM course to solve the case questions. The students figured out how to select products for the forward pick area using the two heuristics given in the case study and ranked the products correctly. However, they did not note the requirement of ranking the storage locations because it was not explicitly mentioned in the case. All the students were familiar with MS Excel Solver for solving optimization problems and chose it to solve question 2 in the case study. However, the limit on the number of variables (maximum 200 variables) imposed by MS Excel Solver emerged as a major hurdle in determining optimal product assignment. Some teams did come up with innovative ways of reducing the number of variables by developing new heuristics on their own so that they could subsequently use MS Excel Solver. However, the optimal solution as desired was not obtained by any team. Most students in the OM course found it difficult to solve the descriptive questions satisfactorily, primarily because of their lack of knowledge of warehousing science. The feedback of the students in the OM course was analyzed, and some changes were made in the case study before prescribing it to the students in the WO course.

There were eight students in the WO course who were grouped into two teams (each consisting of four members) to solve this case study. Because the students were already familiar with all the warehousing concepts and optimization techniques, no preparatory sessions were required. The students were to submit their solutions within one week. Neither team faced any difficulty in using the heuristics as expected. Based on the student response from the OM course, the students from the WO course were forewarned regarding the limitation of MS Excel Solver and were encouraged to try other tools instead. Both the teams chose to use OpenSolver plugin for MS Excel to solve question 2 of the case study. Using this plugin, both teams formulated the optimization problem correctly and obtained the desired results. For the descriptive questions, the answers were close to the desired solution. The question-wise average scores (out of maximum 10) of the students across the two courses are given in Table 1. Questions 1 and 2 carried 30% weight each, and questions 3 and 4 carried 20% weight each.

From Table 1, it can be observed that the students in the OM course found it challenging to solve question 2 (regarding the optimal assignment of products to storage locations) and question 4 (regarding alternative forward-reserve storage arrangement).

Overall, the entire exercise helped gather valuable feedback regarding the readability and effectiveness of the case study. Several suggestions were received to eliminate difficulties in understanding what was expected when solving the case questions. These suggestions were incorporated when revising the case study; however, no major changes were required. The major feedback points are summarized here.

4.1. Use of Technical Note

A common piece of feedback from the students in the OM course was that some basic knowledge regarding warehousing is necessary to approach the case study questions effectively. One student stated, "Theory for the case should be taught before case discussion." This strengthened the argument for the use of a "technical note" for students without any background in technical education. However, this material may not be necessary when prescribing the case study to courses such as WO, where warehousing is taught in class.

4.2. Effectiveness of the Case Study

Several students from the OM course pointed out that this was their first experience using heuristics in a real-life scenario. The comparison of heuristics' performance with the optimal solution provided them with valuable takeaways. The feedback from the students in the WO course was more focused on the intricacies of warehousing discussed in the case. One student stated, "The case study was very helpful and gave us a glimpse of the kind of problems we might solve in the real world." Some students also voluntarily commented that more such cases need to be included in classroom teaching.

4.3. Limitations of MS Excel Solver

The ease of using MS Excel for data entry and to perform computations using these data makes it a natural platform for teaching optimization. However, the built-in Solver in MS Excel has a few problems such as a limitation on the number of variables (maximum 200) and difficulty in checking the formulated models. Additionally, students find it daunting to graduate from simpler MS Excel–based model development to using modeling languages that generally have a text-based interface (Mason 2013). The limitation on the number of variables in the built-in Solver of MS Excel emerged as a major hurdle for the students in the OM and WO courses when solving the case study. This problem can be overcome by using the OpenSolver plugin for MS Excel, which has no limit on the number of variables. The interface of this plugin is similar to that of the built-in Solver of MS Excel. Additionally, OpenSolver plugin works faster than the built-in Solver and offers on-sheet visualization capabilities (Mason 2012). This plugin can be downloaded and installed free of charge. One may refer to Mason (2012, 2013) for more details on SolverStudio and OpenSolver. Based on our experience, we recommend the use of the OpenSolver plugin for MS Excel for solving the case study problems; however, in case the instructor wishes to use any other modeling language/platform, the instructor may advise the students accordingly.

5. Conclusion

This article emphasises the importance of case studies as a teaching tool for helping students apply concepts studied in classrooms to real-life situations,

Table 1. Average Scores of Students in Assignment Questions

Course	Question 1 (30%)	Question 2 (30%)	Question 3 (20%)	Question 4 (20%)	Overall
OM	7	6	8	5	6.5
WO	8	8	8	7	7.8

particularly those regarding supply chain management. Despite being an important part of most supply chains, warehousing has not been popularly considered when writing case studies. The case study discussed in this article attempts to bridge this gap. A brief synopsis of the case study is given in this article, followed by its learning objectives and associated documents. The experience and feedback of prescribing the case study as a classroom assignment in two different courses are then discussed.

The case study helps expose the students to concepts in different areas such as storage strategies, automated warehousing, optimization, and heuristics. Thus, it can be used in different courses such as OM, WO, industrial engineering, supply chain management, and OR. The case study can also be suitably used in different courses at the undergraduate level. The case explores only one configuration of automated warehouses (multiaisle AS/RS). Thus, there are ample opportunities for academicians to develop cases exploring other configurations of automated warehouses such as those using robots, mobile racks, and so on.

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Endnote
[1] The supplemental materials are available at https://www.informs.org/Publications/Subscribe/Access-Restricted-Materials.

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