Proceedings of the 2024 Winter Simulation Conference
H. Lam, E. Azar, D. Batur, S. Gao, W. Xie, S. R. Hunter, and M. D. Rossetti, eds.

PICKING SYSTEM DIGITAL TWIN: A LAB-BASED CASE STUDY

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ABSTRACT

Digital Twins have become a focal point of simulation modeling and analysis in recent years and seems to be gaining momentum. As such, there is a need to more fully integrate practical digital twin modeling and analysis into systems simulation courses. In this paper, we present a lab-based digital twin case study of a pick to light picking system. The digital twin design framework and methodology utilize a simulation model that acts a virtual near real-time representation of a physical picking system. The digital twin can be used to analyze picking system configurations such as alternative picking policies, inventory policies, worker allocation to picking zones, and related decisions.

1 INTRODUCTION

The use of automation in warehousing systems continually grows as the needs for it evolve with labor, supply chain, and end customer requirements. This paper focuses on the use of digital twin (DT) technology to optimize warehousing systems in the order picking processes. With warehousing costs significantly impacted by picking operations, we aim to create a DT model mirroring a real-life picking system to evaluate effectiveness and identify areas for improvement. By integrating real-time and historical data, the model allows for dynamic monitoring and decision-making through easily readable information displays. The research aims to advance the educational value of simulation modeling and contribute to DT theory and application in warehouse logistics.

With the prevalent labor shortages and supply chain issues in recent years, industry has turned to automation and innovative technologies to shore up any existing gaps. One area of concern is the warehousing process, which accounts for at least 40 percent of the total production cost (Leng 2019). Within warehousing processes, picking is the act of selecting individual items to fulfill customer orders and is one of the most cost draining operations in that it takes up 60 to 70 percent of warehousing costs (Chen et al. 2015). A zone picking system consists of a series of shelves or bins grouped into specific areas (called zones), an order management system, and workers and equipment used to collect the items for customer orders. As such, the focus of automation in this area is to reduce picking time. One method of achieving this is to build a digitalized model of the real-world system.

Various simulation methods have been the groundwork for replicating real-world systems in industry and academia. Included in these methods is the concept of DT – which is a "virtual replica of a real-life environment that can be used to test different conditions" (Hercules 2022). The potential of a DT lies in its ability to conduct real-time monitoring for the purpose of evaluation and decision making (Liu et al. 2020). Hence, in creating a DT for an existing picking system, several factors must be considered. These factors are the ways of translating the physical storage characteristics into a virtual world, the method for establishing a connection between the existing ordering system and the virtual model, and how to handle the visual aspect of inventory alerts in the DT.

The purpose of this paper is to create a DT model of a picking system to see the effectiveness of the model in mirroring the real environment for integration into a systems simulation course. This includes using real-time data in conjuncture with historical data to view the health of the real-world system and identify points of improvement. From there, methods can be developed to assist in the selection of an optimal reorder point, compare the real-time picking to the simulated environment, and determine the effects of alternative systems configuration and decisions.

The remainder of this paper is organized as follows. Section 2 presents a summary of related work on DTs. Section 3 provides information on pick to light systems. Our modeling and analysis methodology is given in Section 4. In Section 5, an example case study implementation is presented. We provide a discussion and some additional insights in Section 6. Finally, our conclusions and future work are presented in Section 7.

2 SUMMARY OF RELATED WORK

The use of digital twin to study and optimize warehousing systems has expanded greatly during the last few years. For this section, the focus of the research is on the concepts and industrial applications of digital twins, the incorporation of order picking in a DT and the logistics of decision making through a DT.

As the concept of DT has developed over time, its definition has evolved to fit the needs of industrial applications. For earlier years, DT was referred to as a model or multidisciplinary simulation without consideration for real-time connection with the physical environment (Liu et al. 2021). In more recent years, the basis of DT is a model that links the physical environment and the digital environment in real-time (Liu et al. 2021). In more detail, a DT must contain the following core characteristics: physical system, virtual system, data integration, service system, decision support system and connections between all the dimensions (Coelho 2021). As such, the application of DTs can be found in a wide variety of fields spanning education, medical, warehousing, etc.

In order picking, the priorities of utilizing a digital twin are related to four objectives: high performance, low costs, short throughput times, and high adherence to delivery dates (Kauke et al. 2021). Through these priorities, a DT model needs to be able to analyze order data, identify current inventory levels and indicate transport and workers available. On order generation, Kauke et al. (2021) indicated that their model can draw order intake from the connected system, assign it to a cluster, and use that cluster for predicting order trends. Auto-replenishment initialization occurs when the system is started with these orders being classified into different pick densities (Chan et al. 2011).

One of the main reasons a DT model is used is in aiding the decision-making process of a picking operation. This makes the decision support system immensely important as it allows for interaction between the decision maker and the digital twin (Coelho 2021).

Building from this research, our goal is to enhance the decision-making process of a DT by developing an easily readable information display of relevant statistics in the DT that is self-updating as the model runs. In the design of this model, we utilize the framework of establishing a data connection to the order intake system and the theories behind the decision support system. By making relevant statistics easily readable, we hope to use this model to enhance education in simulation modeling and the theories behind a functional digital twin.

3 PICK TO LIGHT SYSTEMS

The picking system that is being used as a basis for the DT is a pick to light (PTL) system. This is defined as an order picking technology found in warehouse and distribution centers which uses lights/LEDs on racks or shelves to guide the order picker (Lucas 2021). Compared to older picking methods, the advantage of a PTL system is in the digitized display which provides a visual aid for the order picker on where to pick items.

Unlike the traditional paper list and radio frequency (RF) picking systems that rely on having all order information transmitted to the picker on a single document or device–PTL systems have the order information transmitted to the various pick locations. An example, of a pick to light system is shown in Figure 1. To enable this efficient picking, PTL systems usually have the following principal components:

lighting terminals with multiple lights and an alphanumeric LED screen that indicates the quantities required for picking, a barcode scanner which shows the totes or cartons corresponding to an order, and a PTL software controlling the lights and communicating with a warehouse management system (WMS) or the like (Lucas 2021).

For the order picker, the PTL system is a repetitive process where each order is typically picked independent of any other orders. To begin, the picker usually scans a barcode containing the order details. From there, the PTL system is activated by lighting up the terminals at the necessary pick locations with the pick quantity; this creates a visual path for the order picker to follow. Next, the picker will pick the item at each terminal and confirm the pick by pressing a button on the terminal. If there is a shortage of inventory at the terminal, there are typically buttons where the picker can adjust the quantity picked and this is logged into the WMS. Finally, at the end of the pick, the picker presses another button on the PTL system that confirms that the order is complete.

Figure 1: Example of a PTL system. A three zone PTL system (left) containing bins from which specified quantities of SKUs can be picked. Each bin location (right) has a pick quantity display, lighted pick/confirmation button, and quantity adjustment buttons.

4 METHODOLOGY

We develop a digital twin of a PTL system that can be used in a systems simulation course to demonstrate how DTs can be applied in industry. In particular, the lab-based case study illustrates the process for creating a DT along with the challenges associated with data-acquisition and synchronization of a simulation model with a physical system. The PTL system shown in Figure 1 is a small-scale, commercial pick to light system (Lightning Pick 2024) that is located in our production systems laboratory and will serve as the physical system for this example.

The digital twin framework is illustrated in Figure 2. The physical PTL system is controlled by a PTL management system which releases and tracks orders and utilizes an SQL server to store system data. As the PTL system operates over time, information is passed between the PTL management system and the physical PTL system. A digital twin simulation model is utilized to emulate the dynamic behavior of the physical system. The DT uses the information written to the database of the PTL management system to update the state of simulation in real time.

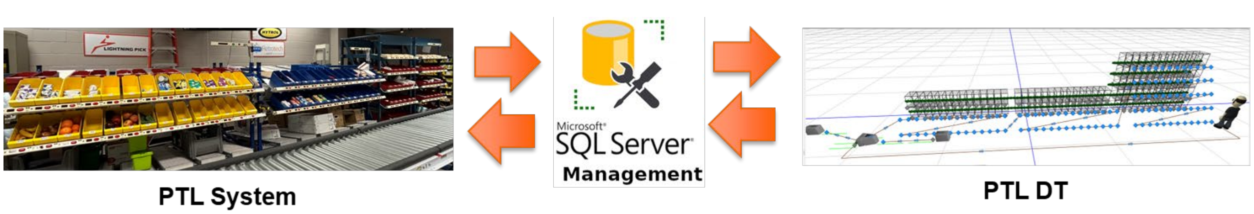

Figure 2: PTL digital twin framework.

To create the DT for a PTL system, we developed a data-driven, discrete event simulation model using the Simio simulation software package (Simio 2024). The DT models the PTL system layout, which includes storage locations, logic for demand, logic for storage and retrieval, and material handling equipment. The picking system is split into three zones (represented by the yellow, blue, and red bins in Figures 1 and 2). An order that is released to the system can be picked by a single picker that travels from one zone to the next or if multiple pickers are used, each picker may be assigned to a zone. In the latter case, the first picker picks the items in the order from Zone 1, places them in a bin then transfers the bin to a second picker that adds the items to the order from Zone 2, and finally the bin is passed to a third picker that adds the items to the order form Zone 3.

Figure 3 outlines the picking process for an order and the points at which data is transferred from the PTL system to the DT model via the PTL management database. In particular, when an order is released for picking in the physical system, the order details are read into the DT including the Order ID. As the pick begins, the picker presses a button on the PTL system which lights up the locations to be picked in the first zone. At this point, the pick locations for the first zone are read into the DT from the PTL database. Knowing these locations, allows the simulation to represent the locations where the simulated picker needs to stop to pick the items. Within the zone, the picker moves to a location and makes a pick. Then the picker presses the pick confirm button. When the picker confirms the pick, the pick complete time is written to the database which signals the simulated picker in the DT that the item pick is complete. This process continues until all items in the zone are picked. The process then continues to the subsequent zones until all items in the order have been picked. When the order is complete, the DT can calculate statistics on the order/system.

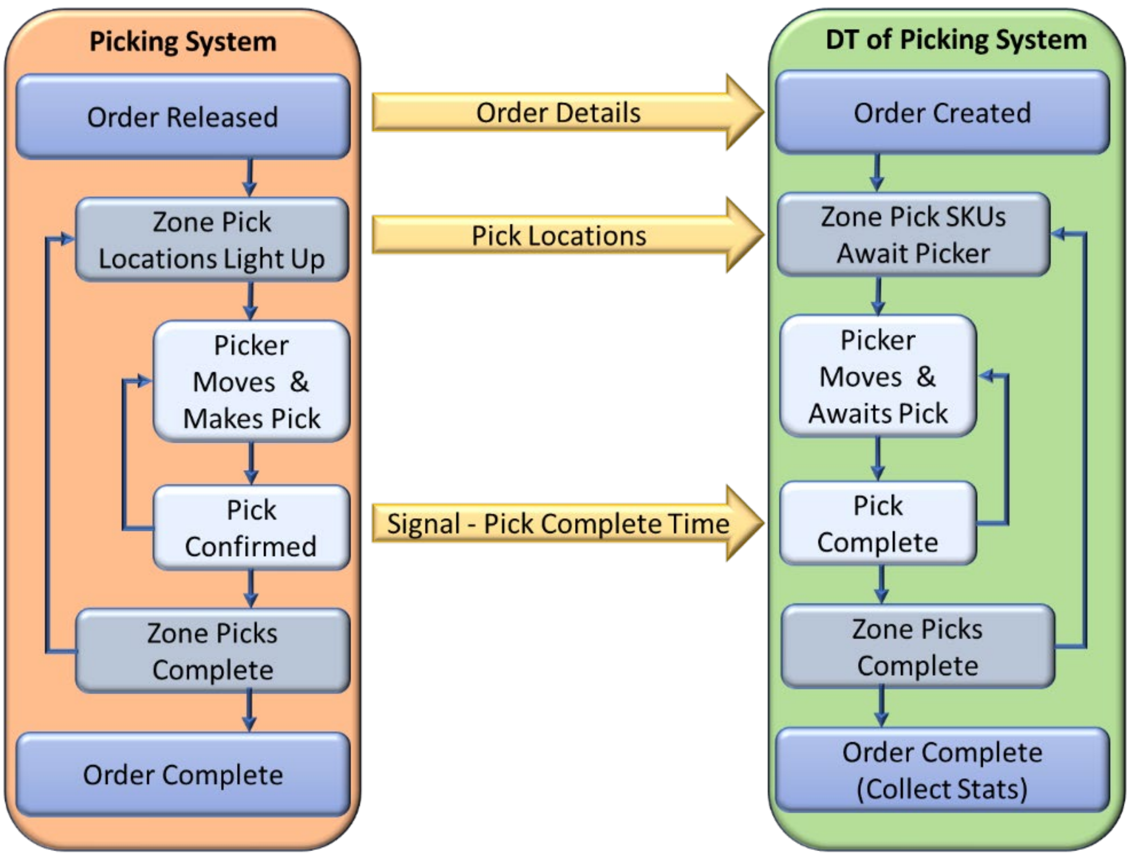

Figure 3: Order picking process that drives the digital twin via data from the PTL management database.

5 EXAMPLE IMPLEMENTATION

To illustrate the application of the PTL digital twin, we conducted an experiment to compare the operational performance of the picking system under two scenarios. In the first scenario, a single picker is used to pick a set of orders, and in the second scenario, three pickers are used to pick the same set of orders. This example could represent trying to determine the tradeoffs among performance measures such as the makespan of picking a set of order (say to meet a shipping deadline) versus the number of picking resources that are being deployed.

For this experiment, we generated a random set of ten orders and loaded them into the PTL management system. We then ran the single picker scenario where the orders were picked in the physical system while the digital twin emulated the picking process. As the scenario was executed, statistical performance measures of the system were calculated in the simulation. Upon completion of the first scenario, we ran the second scenario with three pickers where each picker was assigned to one of the three picking zones can collected system performance measures.

The results of the two scenarios are presented in Table 1. In particular, the results indicate that the three-zone picker scenario reduced the overall makespan of fulfilling the ten orders by ~50% compared to the single picker scenario resulting in a throughput rate of 1.344 orders per minute versus 0.668. However, this increase performance comes at the cost of adding two additional pickers.

Table 1: Single picker versus three-zone picker scenario.

	Single Picker Scenario	**Three-Zone Picker Scenario**
Makespan (min.)	14.95	7.44
Average Order Pick Time (min.)	1.46	1.29
Range of Order Pick Time (min.)	1.12 – 1.97	1.04 – 1.79
Throughput Rate (Orders/min.)	0.668	1.344

6 DISCUSSION

The example implementation of the DT can be used to present an interactive demonstration of digital twins and their function in terms of emulating system behavior and the ability to collect performance measures to compare alternative systems. However, this simple example is just a small fraction of what can be done with the digital twin once it has been created. Other potential example that we are in the process of creating simulation lab case studies include:

- Starting with the current state of the system emulated in the digital twin and simulating the near-term future of upcoming order to determine if delivery deadlines can be met.
- Simulating upcoming orders given the current state of the system to determine if sufficient inventory will be present to fulfill the order and if not, revise the sequence of orders to allow for inventory replenishment before processing the order.
- Integrating the PTL system with location tracking sensors that can track the movement of the worker in the system.
- Adding additional automation to the system such as an autonomous mobile picking robot to compare the cost and benefits of automation along with its capabilities and limitations.

These are just a few of the many possibilities that could be realized and investigated through the application of digital twin.

7 CONCLUSIONS

The focus of this paper has been on the development of a practical case study for the integration and teaching of digital twin concepts and application in systems simulation courses. The application to picking which is a critical aspect of supply chain provides a context for digital twin that is relatable to students without being too complex for implementation. The creation of a DT model mirroring real-life picking systems offers a valuable tool for evaluating effectiveness and identifying areas for improvement. Through the case study, we have illustrated the functionality and potential applications of DT for a simulation class. Future work includes using the DT to set up more extensive experiments for determining picking capacity for different scenarios, running experiments to determine PTL design for zone size or allocation of pickers, and using existing order data to predict bottlenecks and issues down the line (i.e. missing due dates, or out of stock). However, to reach that point, additional work is required to improve the process logic and validation to ensure a robust and reliable digital twin.

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