Simulation Modelling of Chilled Distribution Center for Order Picking Improvement

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Abstract—**This article involves a simulation study on a bottleneck labor intensive order picking operation at a cross docking chilled distribution center for perishable products. The objective is to improve the performance of the system in terms of the order picking makespan. A simulation model that imitates the order picking operation is developed. The model captures major sources of system variability including occurrence and amount of daily demand, availability of workforce, and operator picking speed. The model is validated by comparing the makespan obtained from the model output with historical data from the real system. Preliminary test on the simulation model shows that the model can reasonably represent the real system.**

Keywords— **Simulation, Cross Docking, Order Picking, Pick-To-Light**

I. INTRODUCTION

Cross docking is an important warehouse management concept that is widely used in many distribution centers (DCs). Particularly, cross docking is implemented in DCs that distributed a large number of merchandises to a number of customers, which in most cases are retail stores or smaller regional warehouses [1]. It is especially useful for products that are perishable, e.g. chilled foods, dairy products, which are stored and distributed at low temperature (around 4-6 °C)[2],[3]. These products usually need to be distributed quickly in order to preserve their quality.

In a chilled cross docking DC, merchandises flow from inbound docks to a picking area, and then to outbound docks in a short flow time, usually within 24 hours [4], [5]. The major advantage of short flow times is that it allows the DC to transfer a large number of merchandises [4], [6]. This is equivalent to having high inventory turnovers, which makes the DC more responsive [6], and reduces the DC's inventory holding cost [7].

An important operation in the cross dock chilled DC is the order picking operation. Unlike traditional warehouse where order picking involves item retrievals from storage racks or areas [8], order picking at a chilled cross docking DC is all about matching the incoming merchandises to outgoing orders. Specifically, the operators would manually pick the right amount of merchandises to fill customer orders, which makes it the most labor intensive operation of the DC.

Two of the common order picking systems are paper-based system and pick-to-light system. The pick-to-light system requires considerable investment in both hardware and software. Its advantages are much higher efficiency and accuracy, as well as less labor requirement; therefore, it usually is a preferred system for major retail chains.

Zoning is an important concept that facilitates the process of order picking and put away. In one type of zoning, the total number of orders is separated into batches, each of which is assigned to a zone. That is, more than one batch of orders can be processed at the same time. Thus, this type of zoning is called simultaneous zone picking. Its advantage is that batch size can be arranged to be of different size, which enables the batch picking to be complete at different times. The purpose is to synchronize the order picking with the downstream delivery schedule. However, the major disadvantage of order batching in simultaneous zoning is that there could exist idle time between batches within the same zone. This could occur because operators can finish their assigned orders at different times, so that some operators must wait until all operators finish their orders within the same batch before the next batch can begin [9], [10], [11].

This article focuses on efficiency improvement of the picking operation at a cross dock chilled distribution center (CDC). The motivation comes from the system performance, which indicates that order picking is the bottleneck operation at CDC. The issue is that the system has, on the average, a long makespan, i.e. the operation completion time at the end of the day. This is due to two main sources of system variation, including the available number of operators and the number of orders that could vary significantly from day to day.

In order to reduce the system makespan, alternatives for picking operation improvements are proposed. However, it is very difficult to evaluate these improvement alternatives for such a large system that has manual operation. Therefore, a discrete-event system simulation model is developed to imitate the behaviour of the system. The objective of this article is to present the logic of the simulation model for the current system. Preliminary results from the simulation runs are also reported.

II. Chilled Distribution Center

A. Products and Orders

At CDC, there are approximately 500 perishable product SKUs in four product categories: large dairy products, small dairy products, processed meat, and ready-meal products. These products flow through CDC in approximate amount of one to 1.5 million units per day, serving almost 3,200 retail branches every two days.

Retail branches are categorized into two groups: high demand (approximately 200 branches) and normal demand (approximately 3,000 branches). The high demand branches may place replenishment order every business day (Mon to Sat), while the normal demand ones are allowed to place orders every two days in either Mon-Wed-Fri schedule or Tue-Thu-Sat schedule. The large number of products and many retail branches combined to be the first major source of system variation.

B. Operations

CDC main operations include receiving items from suppliers, picking the items to satisfy orders, and distributing to those branches within 24 hours. Daily operation begins at 4:00AM. Arriving items are unloaded at the Receiving area, and transferred to a temporary storage area before they are moved to the Picking area. At the picking area, the items are unpacked and supplied to the picking blocks.

In each block, the picking operators scan a product barcodes, and the Pick-to-light system would display the required amount of the product. Then, the operator would pick the indicated amount from the incoming basket, place them onto the outgoing basket, and continue until the last product of the order is picked. The finished basket is then carried to the Transport area for delivery.

C. Zone

The whole picking area consists of many blocks. Each block is a picking work space for up to four operators. These blocks are divided into left and right zones. The total number of order in a day is separated into batches, with odd numbered batches assigned to the left zone and even numbered batches assigned to the right zone (see Fig 1).
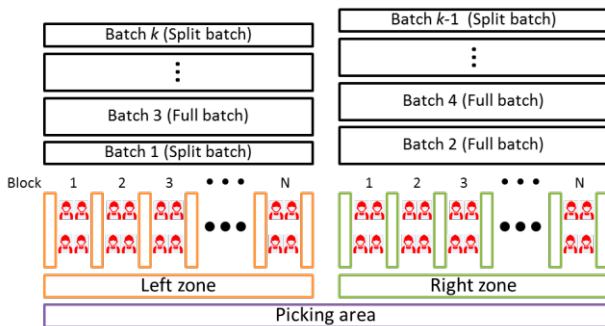

Fig. 1 Zones and blocks in the picking area

To arrange the batch finishing times to be consistent with the downstream delivery schedule, two batching practices are implemented, called full batch and split batch. In a full batch, an order is assigned to a picking block. However, in a split batch an order is split and assigned to two blocks, and the operators in each block is responsible for picking half of the order. This implies that in a split batch, the orders must be combined before loading on to delivery truck. The trade-off between the two batching type is that a split batch has fewer number of orders and can be complete in shorter time, whereas a full batch can process larger number of orders with longer operation time.

D. Availability of Workforce

The 2nd major source of system variation, which is the most critical one, is the daily availability of picking operators. Due to some operators being paid on a daily basis, each day the number of operators that show up to work could be highly varied. For instance, on some Mondays, especially in the rainy season, only 50% of the total workforce would come to work. One cause is that working in a cold environment during rainy season cause some operators to become ill. Another cause is fatigue from backache. On the other hand, holiday season when demand is peaking are the time with high workforce. This is because the operators are compensated at twice the normal wage rate. Throughout the year, the average available workforce is around 75% of required workforce.

III. Simulation Model

A discrete-event system simulation model is a mathematical / logical model that is constructed in a computer. The model is developed in order to imitate real systems such that improvement alternatives can be evaluated without having to interrupt the real operations. This technique is particularly effective in modelling systems that have many sources of variation.

For this study, a model is built to capture the probabilistic behaviors of workforce availability, daily demand, and operator performance (i.e. picking speed) that affect the performance of the picking operation at CDC. The model logic and constructs are shown in Figure 1. The model consists of four parts: (A) generate daily picking demand, (B) generate available picking operators, (C) picking operations, and (D) working shift control.

A. Generate Daily Picking Demand

Part 1 of the model simulates the randomness in daily picking demand. First, an entity representing the total picking orders from all eligible branches is created at the beginning of the day (4:00AM or time 0 on the simulation clock). Then, the entity enters a loop that randomly generates demand of all product SKUs, and the associated random picking speed for that product SKU, one SKU at a time, and keep the two pieces of data in an array. Note that the picking speeds are generated using empirical distributions fitted from historical data. Once demands of all product SKUs are generated, the entity distributes each product demand to all eligible branches (approximately, 1700 retail stores each day). Then, the entity proceeds to combine the demand of all branches into the *k* batches that comply with the delivery schedule. Finally, the entity allocates demands of each batch to

different blocks for the picking operation before the entity is disposed. Sample of logical modules of the simulation models of this part can be seen in Fig 2.
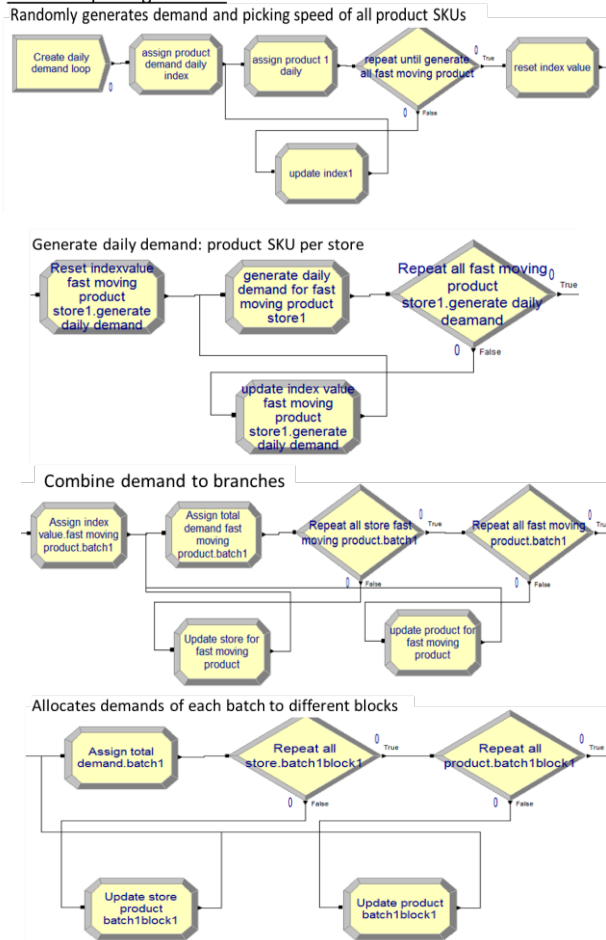

Fig. 2 Model logics for generating daily picking demand

B. Generate Available Workforce

In Part 2 of the model, an entity is created to generate the available number of picking operators those come to work for the day according to an empirical distribution fitted from historical data. Then, the total number of available operators is assigned to the two picking zones. In addition, there are three working shifts starting at 4:00 AM, 8:00 AM, and 1:00 PM. Hence, the total number of operators assigned to each zone is then distributed to the three shifts according to the proportion of operators in those shifts (the proportions are estimated from past data). After the number of operators for each shift-zone is specified, the entity continues to assign this resource to the picking blocks, one operator per block at a time, from block 1 to block b in a cyclical order until all operators are assigned. This will make the number of operators in the block as balance as possible. ARENA model for generating available workforce is shown in Fig 3.
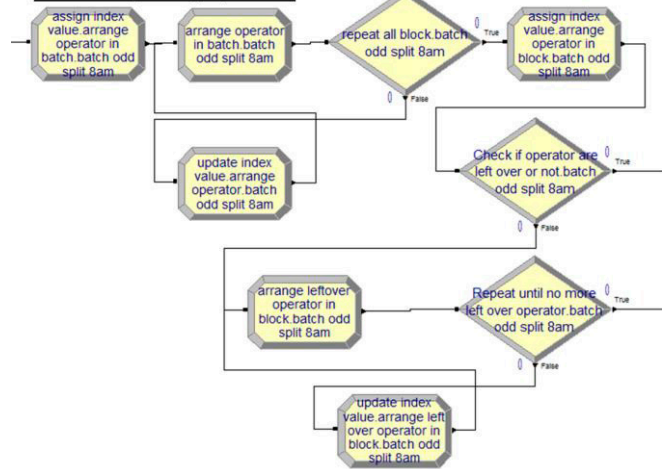

Fig. 3 Model logics for generating daily available workforce

C. Picking Operation

Logics for the picking operation are as follows. An entity is created to initiate the picking operations. Right after its creation, it is duplicated into k entities to represent the k picking batches. The first two entities representing the first batch of left zone and right zone start their picking operations at the beginning of the day, while the rest of the entities wait for signals from their respective preceding entity of the same zone. For each batch, the entity is further duplicated to b entities, one for each block, to represent the picking operation at block level.

After all entities for each zone-block are generated, each of them would seize the required resources including the block capacity and the available picking operators, and delay for the time according to the total amount of items (all SKUs in the orders assign to that block) to pick and randomly generated (from Part 1) picking speed. When the entities in all blocks complete their delays (picking operations), they are batched to become the original entity to represent a complete batch, and the entity sends a signal to the next batch entity of the same zone to begin the operation. Once the batch is complete, the simulation clock time is recorded, before the entity is destroyed. The model logic for the picking operation can be seen in Fig 4.
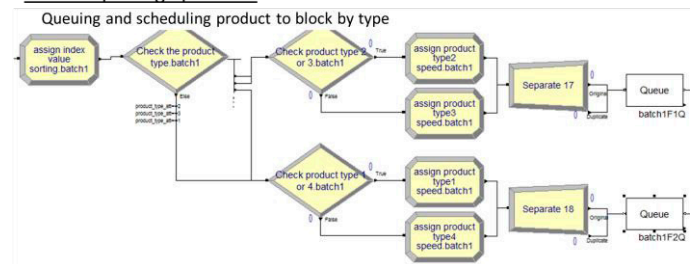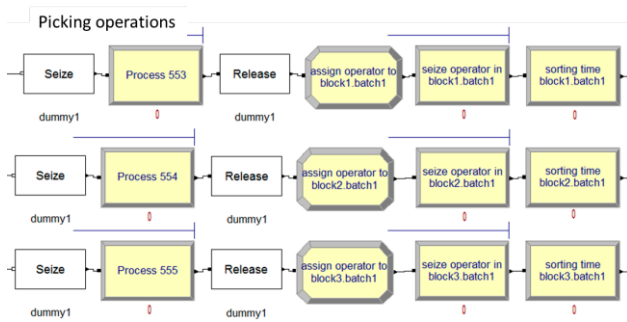
Fig.4 Picking operation logics

D. Working Shift Control

The final part of the model is for number-of-operators control purpose. This is needed because of the three shifts and break times that occur in the middle of each shift. Specifically, for each shift, the available number of operators must be adjusted three times: (1) at the beginning of the shift when operators arrive, (2) at break time, and (3) at the end of the shift when operators leave CDC. The logic for operator break time is particularly non-trivial. This is because, by the policy of the real system, there must always be at least one operator working in each block, i.e. operators must take breaks in alternate fashion. In the logic, an entity is created for the purpose of adjusting the number of operators. That means, the entity, created at simulation clock = 0, would adjust the number of available operators according to the value from Part 2 of the model. Then, it is delayed for four hours until the break time of the first shift. At break time, as one or a group of operators takes a break at a block, the entity keeps track of the number of operators on their break. This indicates that this entity would preempt the picking operation being performed by the picking operation entity (of Part 3 of the model). In the preemption, the "control" entity must wait until the "picking" entity finishes its current SKU before it can preempt and take away the resource (picking operator). The "control" entity is delayed for another hour before it comes back to return the operators who go on break first, and takes away the operators who will go on break next. After the break is over, the entity would delay for only three hours until it adjusts the number of operators who would leave the system at the end of their working shift. The model logic for the picking operation can be seen in Fig 5.
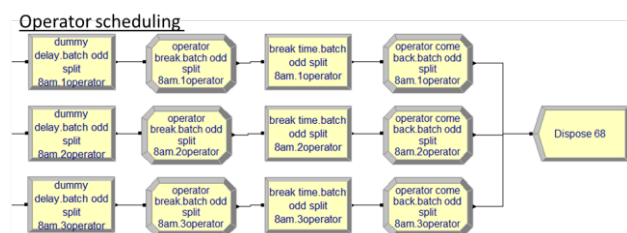

Fig.5 Control logics for working shifts and break times

It is important to note that the model constructed and described here represent only the base case, current picking operation at CDC. Significant changes will be made to the model to capture the logics of each improvement alternatives.

IV. PRELIMINARY RESULTS

Before the simulation model can be used to evaluate improvement alternatives to the picking operation, the simulation model is tested for validation purpose. Model validation is performed to ensure that the model logics work as intended and that the model can produce the outputs that are approximately similar to outputs from the real system. The key measure of system performance for model validation is the makespan, i.e. the finish time of the picking operation for all orders of the whole day.

The model was initially tested for 14 replications. The number of replication was chosen such that the half-width of the 95% confidence interval of the average makespan is within 5% of the average makespan. The results are summarized in Table 1.

TABLE I
SUMMARY OF STATISTICS FROM PRELIMINARY SIMULATION RUNS

Statistics	Value
Sample size	14
Avg. makespan	20.54 hrs; equivalently, 12:32 AM of the next day
SD of makespan	1.44 hrs
95% CI of the avg. makespan	(19.56, 21.51) hrs; equivalently, (11:33 PM, 1:30 AM)
Half-width of 95% CI	0.98; or 0.047% of the avg. makespan

The simulation results are further tested using the following hypothesis based on a one-sample t-test.

$H_0: \mu = 20$
$H_1: \mu \neq 20$

Where μ is the average makespan of the system and 20 is the hypothesized average makespan from the real system. The value is chosen based on historical data and expert opinion, which suggest that, with the level of demand used in this study, the average time at the end of the picking operation is at midnight (i.e. 20 hrs after 4:00 AM).

The *t*-statistics from the preliminary runs is equal to 1.399, which leads to the *p*-value of 0.168. This indicates that the average makespan of the simulation model are not statistically different from that of the real system. Therefore, based on the preliminary runs, the model appears to be valid.

V. CONCLUSIONS

This article involves development of the simulation model that captures the behavior of the picking operation at the chilled distribution center. The distribution center is operated under two major sources of variation: amount of daily demand, and availability of picking operators. Preliminary runs of the model were made to validate that the model can soundly represent the real system through statistical comparison of the key system measure of

system performance, i.e. system makespan. Comparison result indicates that the model is valid and therefore is ready to be experimented further in order to evaluate improvement alternatives to the system, which is the future work of this study.

REFERENCES

[1] T. W. Liao, P. J. Egbelu, and P. C. Chang, "Two hybrid differential evolution algorithms for optimal inbound and outbound truck sequencing in cross docking operations," *Applied Soft Computing*, vol. 12, no. 11, pp. 3683–3697, Nov. 2012.

[2] N. Boysen, "Truck scheduling at zero-inventory cross docking terminals," *Computers & Operations Research*, vol. 37, no. 1, pp. 32–41, Jan. 2010.

[3] D. Agustina, C. K. M. Lee, and R. Piplani, "Vehicle scheduling and routing at a cross docking center for food supply chains,"*International Journal of Production Economics*, vol. 152, pp. 29–41, Jun. 2014.

[4] M. Rohrer, "Simulation and Cross Docking," In *Proceedings of the 27th Conference on Winter Simulation*, Washington, DC, USA, 1995, pp. 846–849.

[5] U. M. Apte and S. Viswanathan, "Effective Cross Docking for Improving Distribution Efficiencies," *International Journal of Logistics Research and Applications*, vol. 3, no. 3, pp. 291–302, Nov. 2000.

[6] V. Seghal, *Enterprise Supply Chain Management: Integrating Best-in-Class Processes*. Hoboken, New Jersey: Wiley, 2009.

[7] E. Frazelle, *World-Class Warehousing and Material Handling*. New York: McGraw-Hill, 2002.

[8]   M. Riccardo, *Warehousing in the Global Supply Chain*. London: Springer, 2012.

[9] A. Guo, S. Raghu, X. Xie, S. Ismail, X. Luo, J. Simoneau, S. Gilliland, H. Baumann, C. Southern, and T. Starner, "A Comparison of Order Picking Assisted by Head-up Display (HUD), Cart-mounted Display (CMD), Light, and Paper Pick List," in *Proceedings of the 2014 ACM International Symposium on Wearable Computers*, New York, NY, USA, 2014, pp. 71–78.

[10] P. J. Parikh and R. D. Meller, "Selecting between batch and zone order picking strategies in a distribution center," *Transportation Research Part E: Logistics and Transportation Review*, vol. 44, no. 5, pp. 696–719, Sep. 2008.