AN ORDER PICKING OPERATION IMPROVEMENT IN A CROSS-DOCK DISTRIBUTION CENTER USING SIMULATION MODEL: A CASE STUDY OF CHILLED DISTRIBUTION CENTER IN THAILAND

BY

RONNAPORN PATTAWEKONGKA

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS ENGINEERING)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
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A Thesis Presented

By
RONNAPORN PATTAWEKONGKA

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Abstract

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The research involves simulation study on a bottleneck labor intensive order picking operation at a cross docking chilled distribution center for perishable products. Cross docking is a popular warehouse management concept used by many retail businesses especially in foods business retailer with scatter branch. Owing to the advantage of customer order turnaround times increasing which, on the other hand, the inventory cost and warehouse space requirements are reduced. The objective in this study is to improve the performance of the system in terms of the order picking makespan and reduce operation cost. 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. Computational test on the simulation model shows that the model can reasonably represent the real system.

Keywords: Simulation, Cross Docking, Order Picking, Pick-To-Light

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Chapter 1
Introduction

1.1 Problem statement

Cross docking distribution center (DC) usually operates in a way that items flow through the DC, from inbound docks to outbound docks, with a minimum flow time Rohrer (1995). For a pure cross docking DC, all items do not have to be recorded as inventory in the DC data system, because the items are already packed and labeled for the final destination Apte & Viswanathan (2000). However, for a traditional warehouse that incorporates cross docking, a so-called hybrid warehouse, items are received as incoming inventory, then retrieved, packed, and labelled before they are delivered usually within 24 hours Apte & Viswanathan (2000).

The main advantage of cross docking is the short flow times that enable the DC to handle a high volume of items Rohrer (1995) and Liao et al. (2012). This increases the inventory turnover, which would improve customer responsiveness Liao et al. (2012). In addition, high inventory turnover can reduce the total inventory level while satisfying the same level of demand, i.e. inventory holding cost, at the distribution center Sehgal (2009). Therefore, cross docking has been widely used at many distribution centers that distribute numerous items to a large number of customers (smaller DCs or retail stores) Liao et al. (2012).

Temperature control or chilled cross-docking DC is especially critical for the distribution of perishable goods, such as frozen foods, dairy products. This is because their quality might deteriorate while they are flowing through the supply chain. With cross docking, threaten of defrost and decay can be effectively avoided in order to ensure food safety and preserve quality Boysen (2010) and Agustina et al.(2014).

Order picking is an important process in a DC. For traditional warehouse, it involves retrieving items from storage to fill a specific order Manzini (2012), Frazelle (2001) and Yu (2008). However, for cross docking DC, order picking mostly involves matching the amounts of incoming items with the quantities in customer orders. In other words, the operations usually include manual picking the right quantity of items and picking them to fill customer orders. This is, therefore, the most labor intensive operation in a cross docking DC. Efficiency of the order picking operation plays a significantly role in maintaining and improving customer service level Yu (2008), Jane and Laih(2005), Petersen (2002), Dallari et al.(2009), Won and Olafsson (2005), Gu et al. (2007).

In Thailand there are two widely used order picking systems: paper pick lists and pick-by-light systems. Advance DCs of large retail companies usually invest in hardware and software of a pick-by-light system in their cross docking DC due to its efficiency, less human resource requirement, and higher accuracy. Pick-to-light, one type of pick-by-light systems, improves the processes of picking and putting away using lights Sehgal (2009). With pick-to-light, the amount of time a worker needs to search for the next item to pick can be reduced, as well as picking accuracy can be improved Pazour and Meller (2011). The system typically consists of lights and displays which indicate the order location and required quantity for the worker to pick items to satisfy the order at each light. High accuracy is achieved by the system setting, where the worker is allowed to pick one SKU at a time. As the workers scan the item, the lights above the correct bin locations would guide the workers to pick or to put away, according to the quantity of items on the display Jane and Laih. (2005).

In some systems, the workers have to press a button to confirm that they have placed the items to the correct bin Guo et al. (2014). In addition to reducing search time and improving accuracy, the pick-to-light system also allows for a varying skill workforce because the system requires very little training time Jane and Laih. (2005).

The total picking area may be separated into different zones for two purposes. In some systems, zoning is designed to separate areas for different SKUs. That is, workers in each zone are dedicated and responsible for the SKUs within the respective zone Jane and Laih. (2005) and Petersen (2002). This type of zoning may be called, sequential zone picking, where picking is performed for one order in one zone at a time, then the order is sent to the next zone. That is, an order is complete after it visits all sequential zones. Advantage of this type of zoning is that there is no need for a downstream picker Jane and Laih. (2005) and Parikh and Meller(2008).
In some systems, zoning is made to facilitate picking and put away of different orders.

In other words, the total number of orders in a day is divided into several batches; each batch is then assigned to a zone where workers are responsible for the assigned batch of orders. This zoning is known as simultaneous zone picking, where all SKUs needed for all orders in each batch are picked and put away simultaneously from all the zones Jane and Laih. (2005) and Parikh and Meller(2008). Advantage of the simultaneous zone picking is that picking time is usually shorter. However, with this type of zoning, orders need to be consolidated using a downstream picking system, which requires a high investment. Furthermore, there may be idle time when the workers have to wait until all the workers finish the current orders in the same batch before the next batch can begin Manzini (2012) , Jane and Laih. (2005) and Parikh and Meller (2008). This type of zoning is appropriate where there are a large number of SKUs, considerable number of customers with moderate to large orders Manzini (2012).

Selecting the type of zoning depends on various factors, such as space limitation in the DC, design and layout of the DC, etc. For instance, a temperature control DC is usually smaller than regular DC for non-food products. Thus, as the number of SKUs increases, sequential zoning may not be possible, and simultaneous zoning may be used. Moreover, some DCs have dedicated docks for receiving and delivery, while other DCs with limited number of docks may have to share them.

This article involves a study to improve operational efficiency at a case study cross dock chilled distribution center (CDC). At this CDC, there are approximately 500 perishable product SKUs with four product categories (large dairy products, small dairy products, processed meat, and ready-meal products) that flows through the center with 1 to 1.5 million units per day for serving almost 3,000 branches every two days.

At the CDC, there are two major sources of variability in the system that causes long system makespan, i.e. the elapse time between CDC starts and finishes its operation. The two sources of variability are the number of replenishment orders and the number of picking workers that come to work. The performance data show that Picking Department is the bottleneck in CDC. The Picking Department has the most labor intensive operation in CDC with the duty to manually fulfill branch order using pick-to-light system. The operation blocks are divided into two zones (left zone and right zone), and the total daily demand is separated into k batches. The simultaneous zone picking is applied with the batch-by-batch working procedure. As a result, there are some idle times from one batch to the next throughout the day that present opportunity for improvement.

In addition, to reduce the operation time in some batches so that batch finishing times can be arranged to comply with delivery schedule, two batching practices, called full batch and split batch, are implemented. In a full batch, an order is assigned to one picking block, whereas in a split batch an order is split into two blocks, and the workers in each block is responsible for picking two product categories. With the two batching, there is a trade-off between smaller number of orders with less operation time in a split batch and larger number of orders with long operation time in a full batch.

With the objective to reduce the system makespan and the total labor cost, improvement alternatives for picking operation are proposed that includes combining batch and sharing resource. The improvement alternatives are evaluated using a discrete-event system simulation model. Real operational, cost, product and demand data are collected from an industrial user to construct the model. Statistical analysis of the simulation results is then conducted to determine the most appropriate improvement alternative for CDC.

1.2 Objectives of the thesis

As mentioned earlier, to handle two major sources of variability in the picking system and effectiveness trade-off under operation constrain. The objectives of this thesis are:

(1) To construct a simulation model that represents the picking system in the chilled cross dock distribution center (CDC) under study.

(2) To evaluate improvement alternatives including combining batch and sharing resource method that reduce the picking system makespan and the total labor cost.

1.3 Organization of the thesis

The remainder of this thesis is organized as follows. A literature review that describes previous research studies related to cross docking warehouse's performance improvement is given in Chapter 2. Chapter 3 describes characteristics of the chilled cross docking distribution center (CDC) under study. Methodology containing logics of the simulation model that imitates CDC is explained in Chapter 4. Then, in Chapter 5 a computational experiment that evaluates the improvement alternatives through simulation, results, and analysis are provided. Finally, conclusion and recommendations that summarize the appropriate procedure with order picking in chill distribution center in the study are given.

Chapter 2
Literature Review

2.1 A review of cross docking distribution center

A comprehensive literature review on warehouse operations that classify the problems by basic warehouse functions, from receiving to shipping, can be found in Gu et al. (2007). Most recent relevant studies to cross-dock warehouse involve truck scheduling (Yu and Egbelu, 2008; Boysen, 2010; Liao et al., 2012; Assadi and Bagheri, 2016; and Keshtzari et al., 2016), operation scheduling (Chen and Song, 2009), job assignment problem (Choy et al., 2012), dock assignment and its variants (Miao et al., 2009; Liao et al., 2013; Kuo, 2013; Luo and Noble, 2012), and vehicle routing problems that features cross-dock warehouses.

2.1.1. Truck scheduling

Yu and Egbelu (2008) considered a sequencing problem of inbound trucks at receiving docks and outbound trucks at shipping docks. The decision of the amount of products transferred from inbound trucks to outbound trucks is also included. The objective is to minimize the total operation time (i.e. makespan). The problem is solved using a developed heuristic. Boysen (2010) studied a truck scheduling problem with three objective functions including flow time, processing time, and tardiness of outbound trucks. Dynamic programming and simulated annealing (SA) were developed to solve the problem. Liao and Egbelu (2012) later designed two hybrid differential evolution algorithms for the inbound and outbound truck scheduling problem, that gives an improved performance over their previous algorithms in Yu and Egbelu (2008). Most recently, Assadi and Bagheri (2016) investigated a truck scheduling problem that aims at minimizing the total earliness and tardiness for outbound trucks. An MILP is formulated, and two heuristics, differential evolution and population-based SA, are developed. The heuristics performance is compared with CPLEX for small instances, and among each other for larger instances. Finally, Keshtzari et al. (2016) formulated a new mixed integer linear program (MILP) for the problem and solved it for small problem instances. They also developed a particle swarm optimization that is a hybrid method with a simulated annealing for the large size truck scheduling problem in a cross-dock system.

2.1.2 Operation scheduling

Chen and Song (2009) studied a two-stage, inbound operations and outbound operations, with precedence constraints between the two stages. A Johnson's rule based heuristics that implements Johnson algorithm for first stage scheduling and the longest processing time (LPT) for the second stage scheduling. The performance is satisfactory when compared with CPLEX. A job scheduling problem in cross-dock warehouse with a single docking zone and limited warehouse space condition was considered by Choy and Chow (2012). The problem include truck sequencing, material handling equipment assignment, and dock assignment constraints. The objective is to minimizing the total makespans (or flow time) of all trucks. A genetic algorithm is developed and tested with problem instances with promising results.

2.1.3 Dock assignment problem

Miao et al. (2009) studied a truck-to-dock assignment problem with time constraint where the number of trucks exceeds the number of available docks. Important factors are the arrival / departure truck time windows, operation time at the dock, and total cross-dock capacity. The total cost to minimize consists of the total operation cost and the penalty cost of unfulfilled shipments. An integer programming (IP) are formulated and solved for small problem instances, while Tabu Search (TS) and genetic algorithm (GA) were proposed for the larger problems. Computational test indicated that TS outperformed other methods.

A variant of the dock assignment problem that also combines truck scheduling is found in Liao et al. (2013) and Kuo (2013). Following their previous work, Liao et al. (2013) integrated the problems as a simultaneous inbound truck sequencing and dock assignment. The total weighted tardiness is minimized under a fixed outbound truck departure schedule. Six heuristics were tested with the ant colony optimization performing the best.

In Kuo (2013), the combined truck sequencing and dock assignment is solved using variable neighborhood search (VNS) and four variants of SA. A different objective function, makespan minimization, is considered. Computational test showed that VNS can provide robust solution to the problem in reasonable computation time. In addition, Luo and Noble (2012) developed an integrated model that optimizes tradeoffs between truck utilization and dock dwell time by maximizing the overall cross-dock operation revenue. The model considers receiving and delivery truck-dock assignment, staging allocation, and load scheduling. A genetic algorithm is implemented to solve the problem.

2.1.4 Cross-docking with vehicle routing problem

Three recent studies have integrated cross-dock warehouse with the vehicle routing problems (VRP). Agustina et al. (2014) considered the vehicle routing and scheduling problem in food supply chains that feature cross-docking distribution center. The objective is to minimize the logistics cost while maintaining delivery service for time sensitive food products. The problem is modeled as an MILP and solved using CPLEX. Customer zoning and hard delivery time windows are applied in order to reduce the problem size such that real world problem can be solved in reasonable time. Chen et al. (2016) focused on the vehicle routing problems (VRP) for cross-docking distribution centers where there are multiple cross-docks for multiple items. Vehicle routing solutions for both inbound and outbound trucks are determined, as well as, assignment of inbound and outbound trucks to receiving and delivery docks. The total cost consisting of inbound and outbound transportation and cross-docking operation is minimized. The problem is modeled as an MILP and solved with a self-learning particle swarm optimization (PSO). Yu et al. (2016) considered an open VRP with cross-docking for a single-item, where incoming vehicles that start at different pick-up points must be scheduled to synchronously arrive at the cross-docking center at the same time, so that delivery vehicles can be dispatched from the center. CPLEX solver and simulated annealing were used to solve the problem.

2.2 Research gap

Based on the literature review, previous studies have formulated the problems regarding cross-docking as MILP (or IP), and solved them using exact algorithms (mostly CPLEX) for small problem instances, and developed heuristics method to solve larger problem instances. A major drawback is that in the real problem the operational data (e.g. picking time, sorting speed, customer demands) that are used in these models, while are assumed to be constant, are mostly random in nature. No previous studies have implemented simulation which can explicitly capture the randomness in the system. Our study aims at closing this gap, and demonstrating the effectiveness of using simulation for solving the picking operation problem in temperature controlled cross-dock warehouse.

Chapter 3
Chilled cross docking distribution center (CDC) description

The chilled distribution center (CDC) considered in this study is perhaps the highest workload chilled distribution center under one of the largest retail companies in Thailand. The distribution center main operations include receiving chilled foods from suppliers, picking them to satisfy replenishment orders from approximately 3,200 company's retail branches, and distributing to those branches within 24 hours. Almost 500 perishable finished products are manually picked in a "pick-to-light" system six days a week. Operational data indicate that picking is the bottleneck operation at this CDC. Therefore, our study focuses on improving this operation with respect to makespan and total labor cost.

The CDC has a limited capacity that can process orders for approximately half the number of branches that it serves per day. Branches are classified into two groups: high demand (approximately 200 branches) and common demand (approximately 3,000 branches). The high demand branches may place replenishment order every day (Mon to Sat), while the common demand ones can only place an order every two days in either Mon-Wed-Fri cycle or Tue-Thu-Sat cycle. Each day all replenishment orders are allocated to six batches to match the daily delivery schedule.

3.1 Merchandise

Products are classified into four types according to their characteristics: (1) large (L) packages dairy products; (2) small (S) packages dairy products; (3) processed meat, e.g. sausage, ham, bacon; and (4) ready-meal products, e.g. bread, lunch box, dessert. Product characteristics are as shown in Table 3.1. The data are estimated from historical records that represent the peak month of a year. Picking speed are modelled using triangular distributions.

Table 3.1 Product category and characteristics

Category	Characteristic	No. of SKU	Avg. No. of order/day/SKU	Picking speed (Unit/man-hr.)
Large (L) dairy product	Low variety, Moderate demand	40	2,700	Tri(900, 950, 1,000)
Small (S) dairy product	Moderate variety, High demand	100	4,800	Tri(1,200,1,250,1,350)
Processed meat	Moderate variety, High demand	100	3,400	Tri(1,000,1,200,1,250)
Ready-meal	High variety, Low demand Fragile, various shapes	250	1,700	Tri(1,400,1,450,1,500)

3.2 Working zone

For cost saving on temperature control, as showed in figure 3.1, the CDC is designed to have smaller overall size, smaller temporary storage area and fewer numbers of docks than common distribution centers. The CDC has three working areas for the three main operations: Receiving, Picking, and Transport. The Receiving area and Transport area share the same docks for unloading and loading, respectively. The Picking area is the lowest temperature area and uses Pick-to-light system. The system consists of *n* blocks, and each block has *m* lights – one light for an order. Due to docks' limited capacity, these blocks are divided into left zone and right zone, where each zone alternately sends picked products to be loaded at the dock.

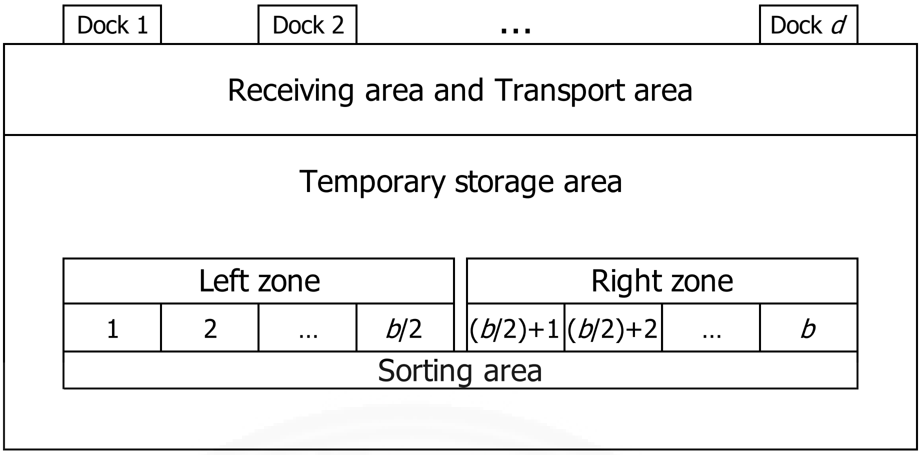


Figure 3.1 CDC layout

3.3 CDC operations

CDC daily operation starts at 4:00AM. The merchandises are delivered by suppliers and unloaded at the Receiving area. Receiving schedule is arranged by product characteristics such as size, weight, package, etc. Then, the received merchandises are moved to the temporary storage area before transferred to the Picking area to be unpacked and sent to picking blocks.

The operation in each block begins with picking operators scanning the product barcodes. The Pick-to-light system would show the amount of product ordered by a branch on the light over the basket. Then, the operator would pick products from the incoming baskets in the indicated amount, place them onto the outgoing basket, and push the confirmation button to finish picking one product before beginning the next product. The process repeats until the last product is picked, then the finished basket is transferred to the Transport area to be loaded onto truck by the carrier.

3.4 Batch and working zones of picking operation

Each day's total orders are divided into k batches. The b picking blocks are assigned to two working zones, (b/2) blocks for right zone and (b/2) blocks for left zone. Both zones are set to begin at the same time, but may finish at different time. Odd batch number are picked in the left zone and even batch number in the right zone. Odd batch and even batch must work in sequence, i.e. batch 3 can start after batch 1 is finished, and so on, as shown in the Table 3.2.

Table 3.2 Picking zones and batch

Left Zone	Right Zone
Batch 1 (Split batch)	Batch 2 (Full batch)
Batch 3 (Full batch)	⋮
⋮	Batch k-1 (Split batch)
Batch k (Split batch)	

Each batch is designed as either full batch or split batch. Full batches and split batches are different in their block-product allocations. A full batch means that all four product types of a particular order are picked by one light address. However, in a split batch, one order is split and assigned to two address lights, each light has two product types. For example, the first address light in block 1 and the first address lights in block (b/4 + 1) are paired to make up of the same order, but different in product assignment (see Figure 3.3). The four product types are grouped so that workloads between the two lights are balanced and compatible for delivery, e.g. L dairy product is separated from fragile ready-meal. In the current system, batches 1, (k-1), and k are split batches, and full batch is applied to all other batches (2, 3, ..., k-2).

Regarding efficiency, a split batch can process approximately half the number of orders that a full batch can process, with shorter batch finish time, but not shorter by half. This indicates that a full batch is more efficient than a split batch. The reason for using a split batch on batch 1 is that CDC needs to push the first batch out to the Transport area as early as possible to comply with the delivery schedule. Similarly, using split batch on batches (k-1) and k is to finish the last batch of each zone as soon as possible. The product assign to full batch and split batch is present in the Figure 3.2

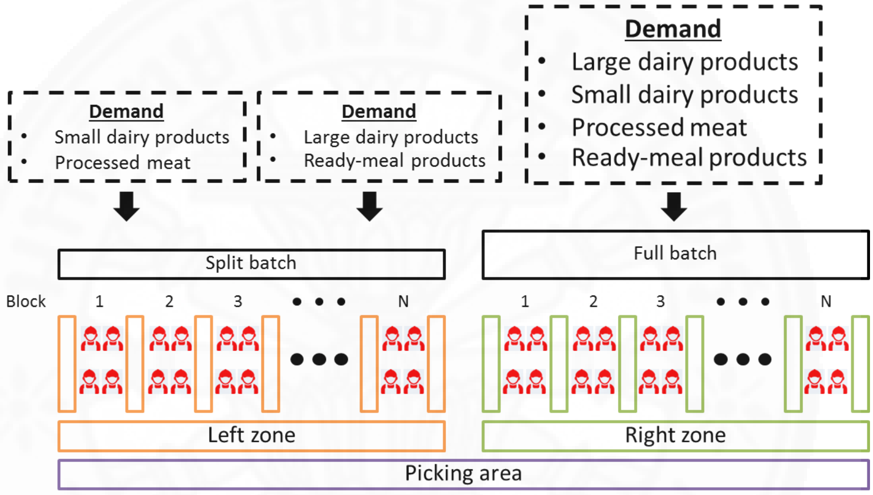


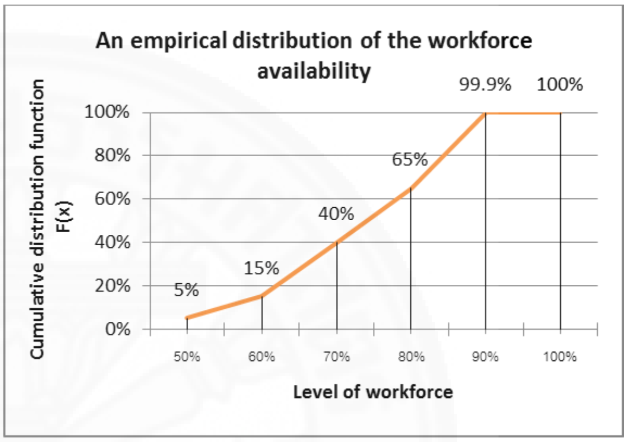
Figure 3.2 The product assign to full batch and split batch

3.5 Picking operator availability and allocation

Picking operation is totally performed by operators, who are mostly paid daily for low skilled operators, or paid monthly for high skilled operators. Each day the number of operators that come to work is highly varied. Days with small number of available operators are some Mondays in the rainy season, where the total number of operators that show up could be as low as 50%. This is because working in a very low temperature control environment during rainy season may cause some operators to catch cold. Season sickness is in addition to a usual number of operators that miss work due to fatigue, mostly from back pain. On the contrary, holiday season with peak demand are days with high workforce because the operators are paid twice as much per day. On the average, each day CDC has approximately 70-80% of required workforce available. The lack of workforce is a very critical issue at CDC. An empirical distribution of the workforce availability is as shown in Table 3.3.

Table 3.3 Empirical distribution of workforce availability

Level of workforce, *x*	Probability mass function, *f*(*x*)	Cumulative distribution function, *F*(*x*)
50%	0.05	0.05
60%	0.10	0.15
70%	0.25	0.40
80%	0.25	0.65
90%	0.349	0.999
100%	0.001	1.0



In each day, available workforce is allocated to blocks as balanced as possible. In a full batch, block 2, and so on, until the last block, then the process repeats until the last operator is assigned. This indicates that there are usually unbalanced numbers of operators in each block. For a split batch, operator assignment is also in sequence, but with a pair of operators assigned to two blocks that make up for an order. Specifically, the first pair of operators are assigned to block 1 and block (b/4 + 1), the second pair to blocks 2 and (b/4 + 2), and so on, until the last operator is assigned (see Figure 3.3).

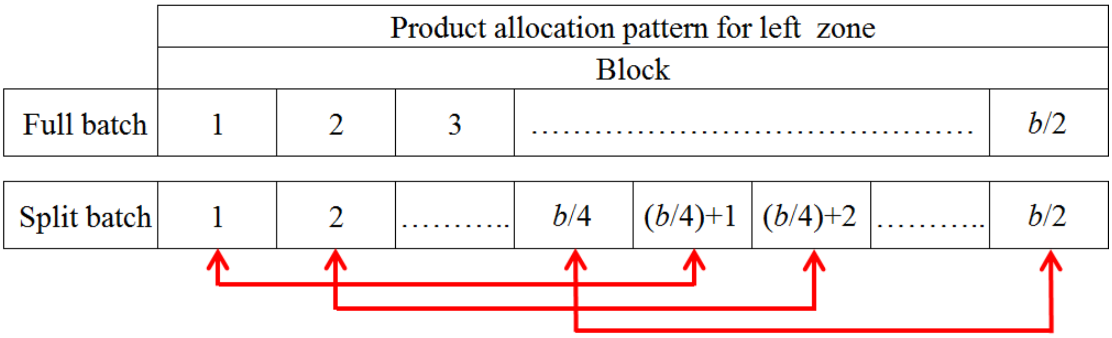


Figure 3.3 Operator allocations to blocks

The required workforce is N operators per day. There are three shifts, starting at 4:00 AM, 8:00 AM, and 1:00 PM, see Table 3.4. There are four scheduled periods for operators' breaks, 8:00 AM, 12:00 PM, 5:00 PM and 9:00 PM. Each operator has a one-hour break (according to fixed break schedule at meal time), and must finish their picking assignment before getting off work at the end of the shift. The policy for taking breaks are as follows: A maximum of four operators can be allocated to a block. For a block with four operators, two operators can take a break at a time. If there are two or three operators in a block, then one operator must remain working, while the other operator(s) can take a break.

Table 3.4 Picking operator allocation

	Picking area	Shift			Total
		4:00 AM	8:00 AM	1:00 PM	
% workforce	Left zone	30%	7%	14%	51%
	Right zone	39%	10%	-	49%

Chapter 4
Methodology

The approach to developing the system is computer simulation. Current system and five alternative situations is constructed base on logical and historical data. Due to uncertainties in the daily level of workforce, daily demand, and operator performance (i.e. picking speed), a discrete-event system simulation model is constructed to imitate the picking operation at CDC.

To build the simulation model, picking operation process must be clearly understand as in the Figure 4.1

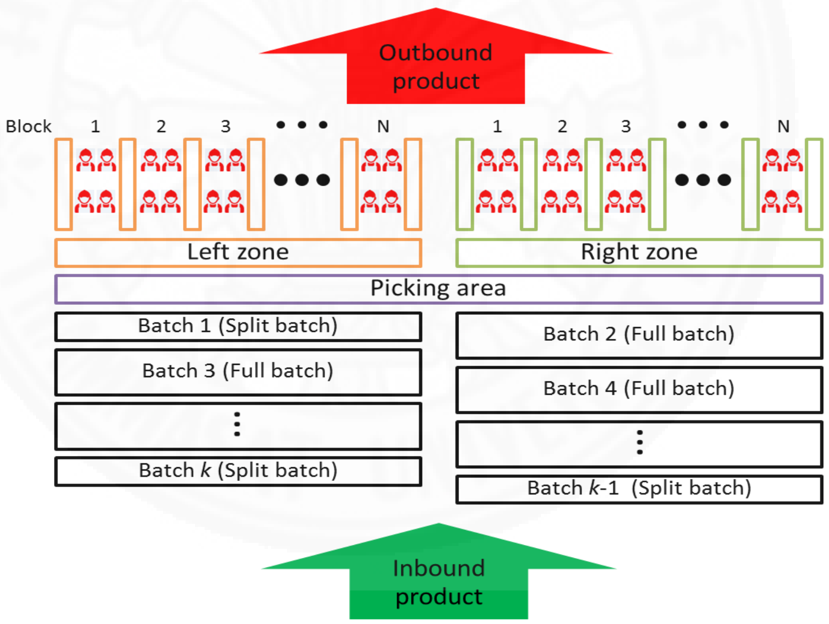


Figure 4.1 the picking structure with batch schedule.

There are two operation zone, left zone and right zone, which simultaneously run. The incoming products are flow from inbound way by batch schedule through the picking area which product is manual sorted by branch order. The finished order will out from the outbound way. Every block in each batch must be finished to begin the next batch. There are four operators working in each block which have difference shift and performance. Then, the model is constructed as the intended logic as presented in the Chapter 3: Chilled cross docking distribution center (CDC). Finally, the outputs are recorded from the simulation run analysis. So the input data and output data must be prepared as presented in the Table 4.1

No.	Input data	Output data
1	Nature of distribution center prototype	Makespan
2	Product category and characteristics	Operator wage cost
3	Logical of picking operation	
4	Batch and working zones of picking operation	
5	Picking operator availability and allocation	
6	Picking operator working speed per product category	
7	Historical demand per day	
8	Operator wage per hours	

Table 4.1 Summary of inputs and outputs in the simulation model

4.1 The base case model construction

The base case model constructed in Arena version 14.0 contains four sub-models as shown in Figure 4.2.

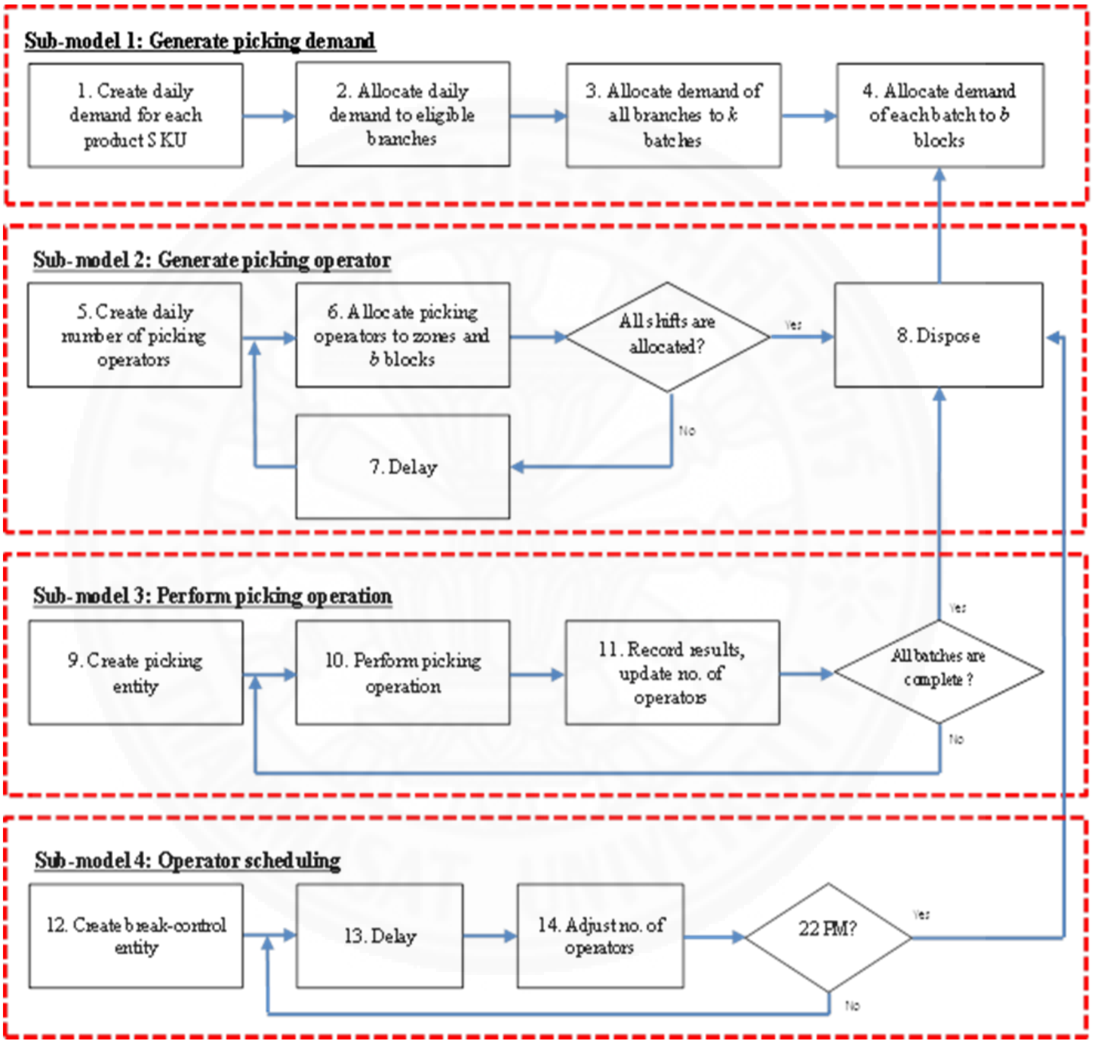


Figure 4.2 Logics of the simulation model

The first sub-model consists of four steps. In Step 1, an entity is created and sent to a set of logic modules that generate demand for each of the 500 SKUs, and the corresponding picking speed for each product SKU following the empirical distribution listed in Table 3.1. After all demands are generated, the entity allocates each product demand to all eligible branches that can place orders on the day in Step

2. Then, in Step 3 the entity continues to allocate the demand of all eligible branches to the *k* picking batches according to the scheduled delivery routes. Finally, in Step 4 the entity is directed to allocate demands of each batch to the *b* blocks for the picking operation before it is disposed.

In the 2nd sub-model, another entity is created in Step 5 that triggers the random generation of available number of picking operators for that day according to the empirical distribution in Table 3.3. The total number of available operators is then allocated to the two zones for each of the three working shifts in Step 6: at 4 AM, 8 AM, and 1 PM according to the percentage specified in Table 3.4. Specifically, the entity assigns 30% and 39% of the total available operators to the left and right zones, respectively, at 4 AM (simulation clock = 0). The entity goes on to allocate the operators in each zone to *b* blocks according to batch type (full batch or split batch) as described in Section 3. Then, the entity checks the simulation clock to see whether operators are allocated to all shifts. If not, then the entity is sent to a delay time of four hours in Step 7. At 8 AM (simulation clock = 4), the entity assigns additional 7% and 10% of the total available operators to the left and right zones, and then allocate them to the blocks. The entity checked the simulation clock again and is delayed (Step 7) for another five hours before assigning the rest (14%) of the total available operators to the left zone and its respective blocks (Step 6) at 13 AM. Finally, this entity is disposed.

The picking operation logics are in sub-model 3. First, an entity that triggers the picking operations is created. Then, it is duplicated into *k* entities, one for each batch. The entity representing batch 1 and batch 2 (the first batch of left zone and right zone) can begin picking operations right away, while the other *k*-2 entities must wait for a signal from the entity of the preceding batch in their respective zone before they can begin. For each picking batch, because the picking operations in all blocks occur in parallel, the entity is duplicated to *b* entities, where each entity now represents a picking operation at the block level. All *b* entities are sent to perform picking operations at each block, where the picking delay time is a function of the demand of the SKU assigned to that block, the picking speed that are randomly generated from sub-model 1, and the allocated operators to the block from sub-model 2. It is important to note that each entity (at a block) performs picking operation for each product SKU at a time. For example, suppose 30 retail branches and four operators are assigned to one block. Each operator would pick one of the 490 product SKUs, one SKU at a time, and put the right quantity to the branch that order that product. The operators would continue until all product SKUs are picked to the 30 branches. When all entities in all blocks are finished, they are combined into the original entity representing the batch and send out a signal for the next batch in the same zone to begin its picking operation. Finally, the batch finished time is recorded and the entity is disposed.

The last sub-model is essential for controlling the number of available operators at different time of the day (i.e. simulation clock) due to the four break times: 8 AM, 12 PM, 5 PM and 9 PM. At each break time, the number of available operators is adjusted three times according to the logic described in Section 3 (see Table 3.4). For instance, at the beginning of a day, the entity is delayed until the first break time (four hours). At 8 AM, the entity adjusts the number of operators in each block to take into account the operators who take the break first. Note that the operators must finish the current SKU that they are picking before going to the break. The entity goes on a delay of one hour (representing the break time for the 1^{st} group of operators). Then, the entity adjusts the number of available operators due to operators coming back from the break and the rest of the operators taking a break. Then, the entity updates the number of available operators one more time after the 2^{nd} group of operators coming back from their break of one hour. The adjustment process repeats until all four breaks are taken.

4.2 The improvement alternatives construction

The model described is for one configuration of the system. In order to assess the improvement alternatives with different configurations of the system, additional logics are built into the model as follows. First, the entity created in Step 9 is duplicated to match the number of systems to compare. Then, all logic modules in Steps 10 and 11 are also duplicated to represent picking operation of each system configuration. This way all randomness in the model would be generated on the outset. Once the entity is duplicated for system comparison purpose, the duplicated entities would carry with them the exact same random data in all aspects, which ensures that the differences in the system performance are truly from different system configurations.

4.3 The proposed improvement methods

A computational experiment is conducted to evaluate the performance of the proposed improvement methods, which include combining batch and sharing resource at the picking operation as present in the Table4.2

No.	Batch allocation	Human resource sharing	
		Not share human resource	Sharing human resource
1	Splitting batches 1, 6 and 7	1 (Base case)	2
2	Splitting batch 1 only	3	4
3	All batches are not split	5	6

Table 4.2 A six computational experiment

For combining batch, in the current system the first batch and the last two batches are split, while other batches are full batches. It is hypothesized that combining batch could improve the system performance. We investigate the effect of combining batches in three levels: (1) splitting batches 1, 6 and 7 (base case), (2) splitting batch 1 only, and (3) all batches are not split.

The other improvement method considered is human resource sharing at the picking operation, which aims at reducing idle time of operators between the end of one batch and the beginning of the next batch. Without resource sharing, a batch must be completed before the next batch can begin. In other words, operators who finished their picking task at an assigned block have to wait until all blocks are finished. The waiting time is considered the operators' idle time, which vary from operators in one block to another, depending on their finish time. However, with the proposed resource sharing, each operator who finishes his or her picking tasks are assigned to help at another unfinished block that is not fully occupied by operators (i.e. there is a maximum space for four picking operators per block). A operator can only take an early break when there is no available space in any unfinished blocks. As a result, the idle times among all operators are expected to be more balanced and occur with relatively less variation in their timings.

Chapter 5
Computational Experiment

There are a total number are six scenarios (three levels of combining batch and two levels of resource sharing). The number of replication is set at 50 to ensure that the precision of the key system measure of performance is acceptable, i.e. half-width of the confident interval of the average makespan is within 5% of its mean. The experiment results are analyzed using ANOVA. Two system measures of performance are makespan and the total labor cost. The results are as showed in Table5.1-5.2. From ANOVA results, both experimental factors have significant effects on the two responses, whereas their interaction is not significant. A further analysis using Tukey's multiple comparisons is performed as shown in Tables 5.3-5.4.

Table 5.1: ANOVA table of makespan

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Combining batch (a)	2	55.917	27.959	12.23	0.000
Resource sharing (b)	1	14.010	14.010	6.13	0.014
Replication (Block)	49	154.870	3.161	1.38	0.059
(a) * (b)	2	6.529	3.264	1.43	0.242
Error	245	560.117	2.286		
Total	299	791.443			

Table 5.2: ANOVA table of total cost

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Combining batch (a)	2	3893931024	1946965512	16.21	0.000
Resource sharing (b)	1	1507876165	1507876165	12.55	0.000
Replication (Block)	49	14526896247	296467270	2.47	0.000
(a) * (b)	2	44773679	22386840	0.19	0.830
Error	245	29430945566	120126308		
Total	299	49404422681			

Table 5.3: Tukey's multiple comparisons of makespan

Combining batch	N	Mean	Grouping
All full	100	21.1129	A
Split batch 1	100	20.7760	A
Base case	100	20.0763	B

Resource sharing	N	Mean	Grouping
Base case	150	20.8712	A
Resource sharing	150	20.4390	B

Table 5.4: Tukey's multiple comparisons of total cost

Combining batch	N	Mean	Grouping
All full	100	70189.2	A
Split batch 1	100	65536.9	B
Base case	100	61368.8	C

Resource sharing	N	Mean	Grouping
Base case	150	67940.2	A
Resource sharing	150	63456.4	B

Comparison results indicate that (1) for combining batch; the base case performs better than the other two cases in both makespan and total cost, which mean that this improvement method is unsuccessful. On the other hand, sharing resource can significantly improve both makespan and total cost by approximately 26 minutes per day and 4,483.80 THB per day, respectively, over no resource sharing. The results are summarized in Figures 5.1-5.2.

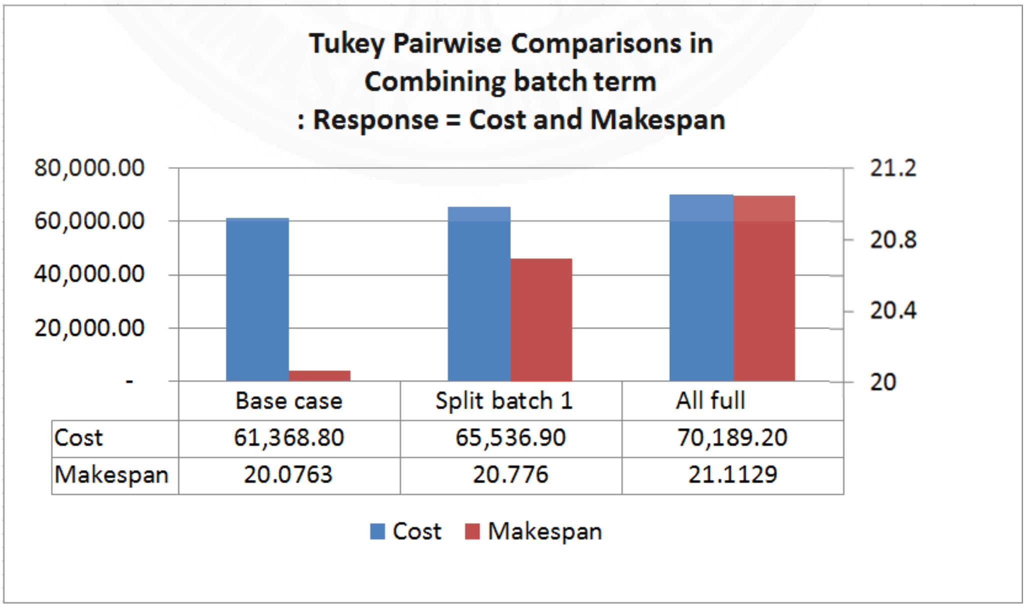


Figure 5.1: Average makespan and total cost in the cases of combining batch

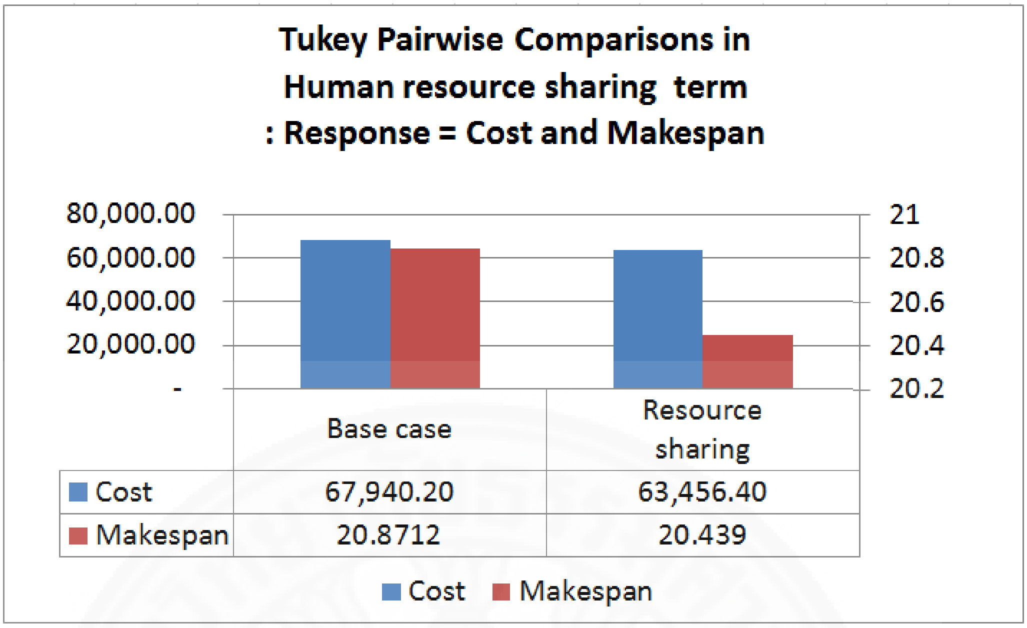


Figure 5.2: Average makespan and total cost in the cases of resource sharing

Chapter 6
Conclusions and Recommendations

6.1 Conclusions

This article presents a simulation modelling and analysis of a chilled cross docking distribution center for a large chain of retail stores. The main focus is on the bottleneck manual picking operation in a pick-to-light order picking system that features simultaneous zone picking. A simulation model that represents the picking operation is developed so that improvement alternatives can be evaluated without disrupting the real system. Major sources of system uncertainties are captured in the simulation model, which include number and size of daily demand from retail stores, availability of workforce, and picking performance of the operators. The simulation model is verified and validated with real system historical data to ensure that the model logics work as intended and that the model can reasonably represent the real system.

Improvement alternatives involve combining batch and resource sharing, which aims at reducing the operators' idle time that occur at the end of each batch due to system variability. The system measures of performance are system makespan and the total labor cost of the operation. Results from computational experiment indicates that sharing resources (picking operators) between blocks, together with splitting the first batch and the last two batches, while keeping the rest of the batches as full batches is the improvement alternative that can minimize both the system makespan and the total cost.

6.2 Summary of contribution of this thesis

There are many research study in cross dock warehouse especially in scheduling, rounding and assignment problem which most solve with mathematical method. But most of real problem are variant variable. This study is focus on providing the method guide line to the operation of order picking in the CDC which was develop in this study. This idea will be useful to the chill cross docking warehouse in Thailand.

6.3 A Publication of this thesis

Some of this thesis is presented and published in an International Conference of Business and Industrial Research 2016 (ICBIR 2016) proceeding as follow:

Pattawekongka, P and Buddhakulsomsiri, J (2016) Simulation Modelling of Chill Distribution Center for order Picking Improvement, *International Conference of Business and Industrial Research*, *Thai-Nichi Institute of Technology*, Bangkok, Thailand, May 12-13,2016.

6.4 Recommendations for further studies

Adding more details which are not concerned in the study for more realistic is the direction we recommend. The model should consider limited storage of cross docking distribution center which in process product and finished product have to share the same area. As occur in the real center, the high turnover rate of picking operator may consider which new coming usually least than the resign. Additionally, the frequent pause time occur during a process in each block from solving error picking should consider in the model.

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