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Simulation and optimization model for a cross-docking distribution center: case study of a railway business

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Abstract

One of the various issues experienced in execution of manufacturing systems in supply chain management is the bottleneck. Bottlenecks frequently occur during operation of real systems. Railway businesses encounter the same issue. In this research, simulation models were developed to explore and eliminate bottlenecks to improve the internal production zone of a rail freight cross-docking center (RFCDC) distributing goods to customers. This research developed the proposed model using ARENA software and performance criteria. Assessment considered data about the output of finished goods, the work-in-process holding inventory, the maximum net profit, and the average total time required. The proposed model demonstrated the best results considering all criteria and compared them to a real operation system, revealing 28.2%, 99.7%, 41.4% and 99.5% improvement in finished goods capacity, work-in-progress, profit and total process time, respectively. The proposed model is recommended for implementation in the RFCDC of this case study as a decision tool for resource allocation and planning.

1. Introduction

In the domestic transportation modes of logistics and supply chains in Thailand, railway businesses seldom rely on logistics activities. Only 1.7% of the overall commodity businesses use them, primarily in land transportation [1]. This is because railway businesses generally have many restrictions that include track availability, availability of rolling stock, bogie length, maintenance schedules, train schedules, and traffic. These factors depend on the choices made by railroad managers [2]. Although the railway businesses have many constraints and are an unpopular transport mode, its advantages are that the logistic costs and pollution are lower than that of other transport modes. Furthermore, railways can handle massive volumes and weights to support industries such as cement, coal mining, and chemical production, as well as transport of agricultural crops and products [3].

Cross-docking-a tactical procedure of logistics and supply chain for distribution-is a procedure progressively implemented for inventory-holding reduction [4]. It allows goods conforming certain policies to remain in inventory less than 24 h [5,6]. Additionally, combining small and larger shipments in same direction, cross-docking is commonly applied in shipments to retail stores to reduce logistics and supply chain costs [7]. Cross-docking has specialized operating layouts. For instance, there is often an inbound zone in which organized scheduling and unloading for inbound vehicles are done, a production zone or break-bulk zone in which organized receiving, sorting, and consolidation are accomplished without storing goods, and an outbound zone where organized scheduling, loading, and planning destinations for outbound vehicles can be done [4,8].

An intermodal terminal of a railway business –one strategy of railway business services-is a transshipment center and temporary storage depot deployed in many transport modes such as rail, road, and maritime shipments for interchanging goods in one batch of shipment between two vehicles using containers. This is performed at a freight distribution center [9]. Cross-docking can be a useful method for improving distribution in logistics

companies. Additionally, it can be practically applied to the intermodal terminals of railway businesses, and is referred to as rail freight cross-docking (RFCDC). This is done at the container freight station (CFS) of an intermodal terminal. The production zone of an RFCDC is at the center to route goods for consolidation. This is an efficient method to reduce costs and upgrade logistic services for intermodal rail terminals [10,11].

Bottlenecks-an issue that usually occurs in execution of logistics systems-are generated by unbalanced operations, improper resource allocation, and inappropriate utilization planning in manufacturing systems due to human errors [12,13] in repetitive processes. These factors cause increased throughput time [14] and cycle time, decreased output rate, and diminish profit in manufacturing businesses [12,15]. Thus, simulation in the form of discrete event systems (DES), which imitate stochastic systems using computer software, is an important technique that can be utilized for analyzing and eliminating bottlenecks, thereby improving productivity.

In recent years, numerous researchers have widely used computer simulation in industries and service centers, as well as in other relevant fields. For instance, [16] simulation models have been employed to reduce vehicle transport in the sugarcane industry [17]. Simulation models have been used to optimize physician utilization to minimize the average patient waiting time and improve the appointment system of a medical center [18]. They have been employed to compare productivity between actual and proposed manufacturing lines [20] and to reduce processing time, as well as to optimize reorder points and inventory holding costs.

In general cross-docking facilities, [8] simulation models have been employed to revamp the performance for loads of operations and [21] to reduce lead times in order fulfillment by optimizing the number of vehicles for transportation. Furthermore, in applications within container terminals [19], simulation models are used measure performance of the outputs, including throughput, resource utilization and waiting times under various terminal resource scenarios, [22] address organization investment issues and improve total investment costs, [23] analyze and assess terminal systems, and [24] to improve container handling systems. These studies have never implemented computer simulation techniques that particularly focus on internal cross-docking in the production zones of railway business cases.

The production zone of cross-docking for rail freight distribution of the current case study often encounters bottleneck issues in the production system. Hence, the primary goal of this research aims to develop simulation models using ARENA software to investigate bottleneck issues in the existing model. Moreover, involving resource allocation and management, we provide a scenario in proposed model to optimize production systems for the case study.

## 2. Materials and methods

2.1 The case study

Figure 1 displays the scheme of this case study, where the business of intermodal rail freight provides services for a transit depot, temporary storage, and distributing goods consisting of beverages, bottled water and canned fruits, to retail companies using rail containerization. Additionally, the container freight station (CFS) or transit shed is examined. This is a space devoted to freight consolidation and cross-docking.
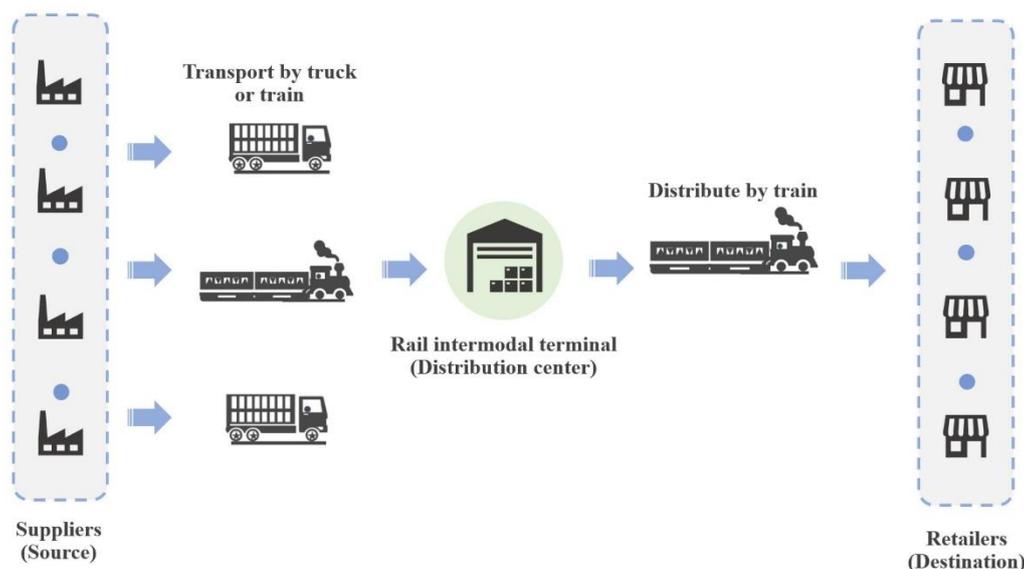
Figure 1 Scheme of the case study.

*2.1.1 Work instructions for rail freight distribution*

Figure 2 displays a diagram of the work instructions for the rail freight distribution facility in this case study. First, products of both less-than-container load (LCL) and full container load (FCL) sizes enter through the terminal gate and arrive in an inbound zone of the container yard. Then, products are consolidated and undergo cross-docking in the production zone. Finally, the products become finished goods that are shipped and distributed to retailers as FCL in an outbound zone of container yard. We developed simulation models analyzing all operations and processes at production zone of this RFCDC before shipping to identify the scope of the case study.
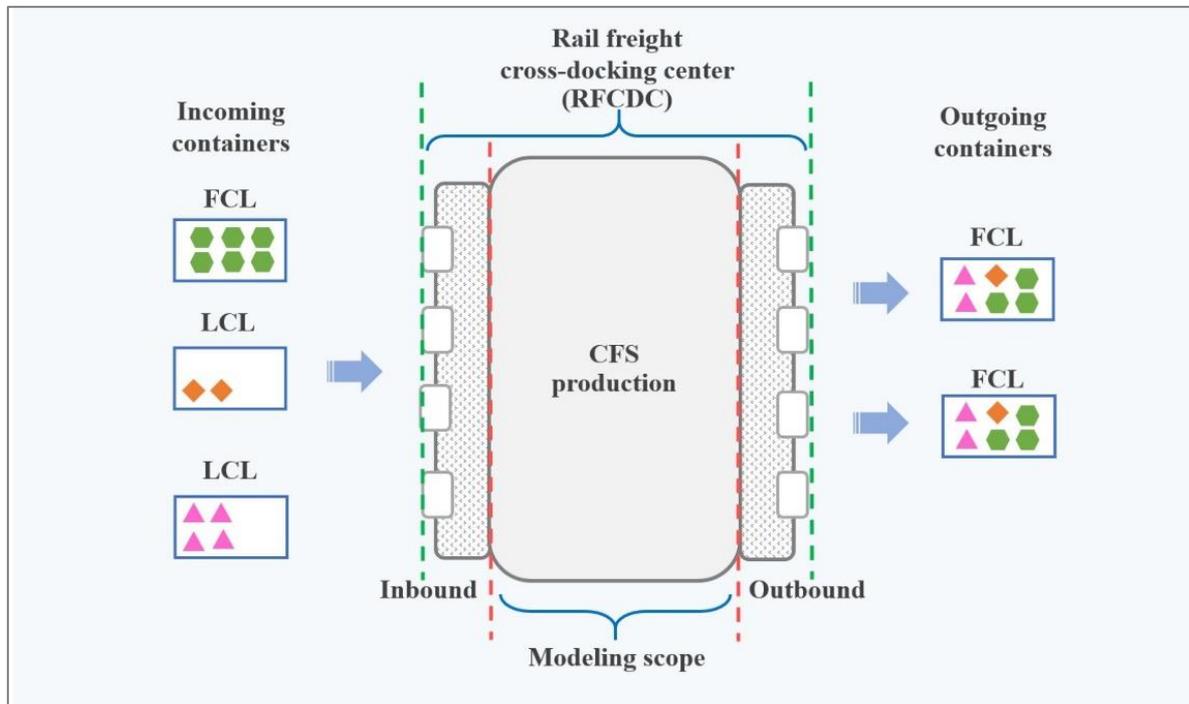
Figure 2 Diagram of the work instructions for rail freight distribution.

2.1.2 Production processes of the rail freight cross-docking center (RFCDC)

Figure 3 depicts processes in the production zone of this study including three important stages, which are the front, cell, and rear production areas. The first step of execution consists of checking and receiving the goods. These are upstream processes that verify and scan data of shipment details such as purchase number, package number, host name, product genres, container genres, and shipping quantities of received product packages. Depalletizing is the second process. It involves removal of plastic wrap, extracting packages from pallets, and preparing them for sorting. Sorting is the third process. It entails segregating product genres in a conversion cell for beverages and bottled water and a separate cell for canned fruits. Accumulating, the fourth process, is were like packages of product genres are collected. Consolidating is the fifth process where packages of various product genres are integrated. Repalletizing, the sixth process, is where the products are placed on pallets prior to shipment. Pallets are next wrapped. New barcodes are printed and the products are then transferred to the next downstream station. Finally, product details are recorded and products are addressed to retailers for shipping.
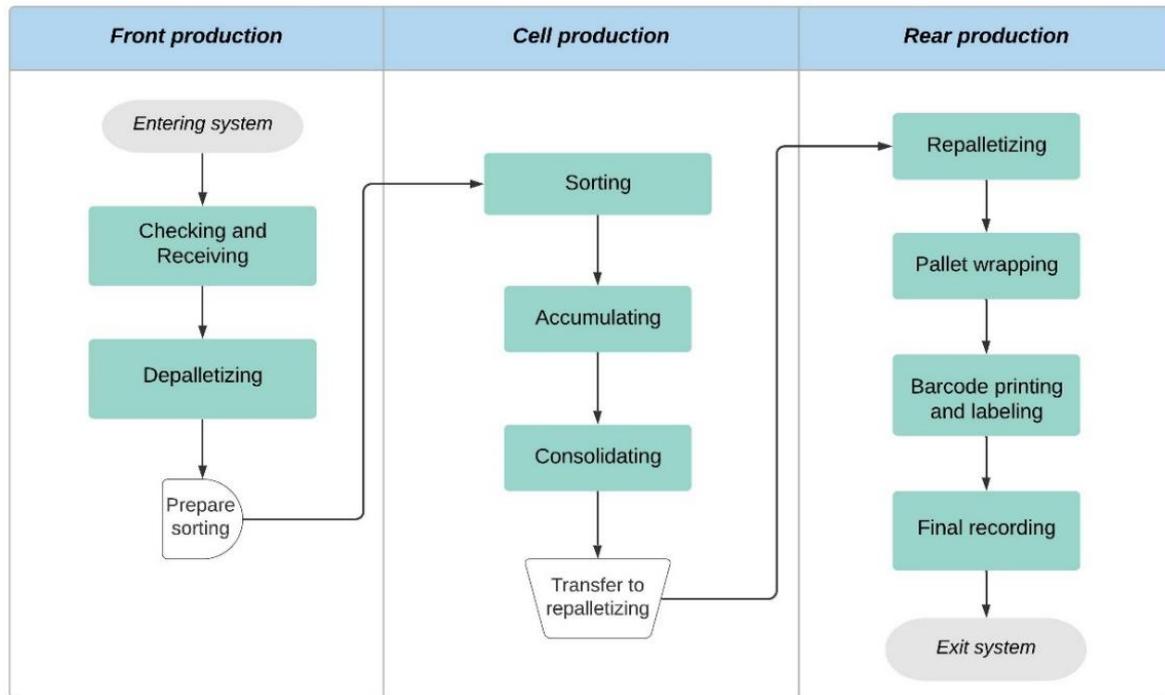
Figure 3 Production process flow of the rail freight cross-docking center (RFCDC).

2.2 Data collection and statistical distribution fitting

2.2.1 Sample size

For determining the sample size in this research, we employed Equation (1) to estimate an appropriate population size:

$$n = p(1-p)\left(\frac{Z}{E}\right)^2 \tag{1}$$

where n is the sample size, p is the population, Z is the z-score at a 95% confidence level, and E is the maximum allowable margin of error, 5%. From this calculation, we obtained the appropriate sample size for data collection, which is a minimum of 385 records.

2.2.2 Data collection

Data collection was done with the acquired sample size. We monitored the data of 5,600 product records covering a period of three months. This was used for the input data in simulation models as below:
- The proportion of products and proportion of containers displayed in Table 1
- Interarrival times of all incoming containers and products
- Processing and transfer times of all processes

The data were used fit to statistical distributions as described in Section 2.2.3.

Table 1 Proportion of products by container genre.

Product segment	Product proportion (%)						
	Beverages			Bottled water		Canned fruit	
Container Type	BV1	BV2	BV3	WT1	WT2	CN1	CN2
FCL	12.2	13.3	3.3	27.8	15.6	20.0	7.8
LCL	36.7	10.4	11.7	13.5	6.5	21.2	0

2.2.3 Statistical distribution fitting

The statistical distribution fitting in this research employed the Input Analyzer tool of ARENA software. Thus, we obtained a probability distribution using the input data of simulation models in Table 2 for the interarrival time of all container genres and Table 3 for the time required by all processes.

Table 2 Proportion and statistical distribution form of interarrival time for container genres.

Container Type	Proportion (%)	Expression (min)	Corresponding p-value
FCL	27.6	11 + 35 * BETA(0.979, 0.992)	0.24
LCL	72.4		

Table 3 Statistical distribution of the production processes.

Process	Expression (min)	Corresponding p-value
Checking and receiving	NORM(0.367, 0.0761)	0.053
Depalletizing	4 + 3 * BETA(0.995, 0.983)	0.19
Sorting (Conversion cell)	NORM(0.201, 0.0553)	0.64
Sorting (Individual cell)	NORM(0.291, 0.0232)	0.57
Accumulating (Conversion cell)	NORM(0.0879, 0.0265)	0.73
Accumulating (Individual cell)	TRIA (0.045,0.064,0.078)	0.53
Consolidating	6 + 2 * BETA(1.02, 1.03)	0.14
Repalletizing	UNIF(8,15)	0.07
Pallet wrapping	TRIA(2.1,2.7,3.4)	0.51
Barcode printing and labeling	NORM(1.5, 0.498)	0.59
Final recording and addressing	11 + 3 * BETA(1.03, 1.01)	0.36

2.3 Simulation model formulation

2.3.1 The existing model

We classified the structural elements for simulation models consisting of entities as product cartons, attributes identifying the characteristics of products, and resources (operators) and machines of all processes. This is depicted in Figure 4. After classifying the structural elements, we constructed the ideal framework for the simulation system as expressed in Figure 5.
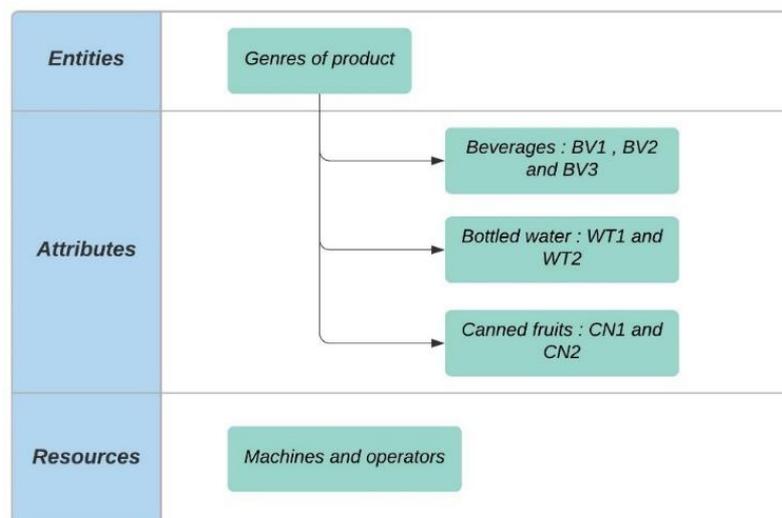
Figure 4 Classification of the structural elements for simulation models.

Input data	Modeling system	Output data
- Interarrival time of entities	- Imitating of all production processes	- Criteria • Finish goods (unit) • Work-in-process inventory (unit) • Total time (minutes/unit) • Net profit
- Operation time of all processes	- Total time counting	
- Product prices	- Finish goods and defect counting	
- Direct production cost per unit	- Profit , revenue and cost equations and reports	
	- Constructing scenerios for optimization	

Figure 5 Ideal framework for simulation models.

Subsequently, we simulated the developed model of the real system. The model was based on the current resource allocation that allowed one operator or one machine to respond, executing a process on each station. From preliminary trials running the existing model, we detected bottlenecks in the existing system at repalletizing and final recording processes. The repalletizing process showed 2,131 cartons waiting entry and an average waiting time 10,596.17 min per carton. Additionally, the final recording process showed 898 cartons awaiting entry with an average waiting time 5,213.57 min per carton. Thus, these processes radically contribute to reducing product output and productivity. They require adjustment for further improvement.

2.3.2 The proposed model for production improvement

For improvement in the real system, we implemented optimization scenarios to overhaul resource allocation. Optimization scenarios acknowledging limitations and restrictions, such as direct labor cost budgeting, capital budgeting and internal liquidity risk management of the case study, were developed by utilizing the lower bound of one operator and upper bound of 3 operators for each operation. The best optimization scenario selected from 2^{11} or 2,048 scenarios, provided a solution allocating two operators in both the repalletizing and final recording processes while using one operator in other processes. Hence, a proposed model was constructed that optimized the scenario.

2.3.3 Criterion of net profit

The criterion of net profit for this case study involved configuring the data module of the simulation model and converting it to ARENA software expressions detailed in Table 4. Additionally, the proposed mathematical model is as follows:

Indices
k = type of product
i = type of machine
j = type of process

Parameters/Decision *variables*
M_i = number of machines, i
x_j = number of operators in process, j
P_k = price of product, k
G_k = output of product, k
S_k = number of salvaged units of product, k, which is a proportion of G_k
D_k = number of scrap units of product, k, which is a proportion of G_k
R = salvage cost
C = scrap cost

Objective function

$$Maximize\ Net\ profit = Revenue - Production\ cost - Defect\ cost \tag{2}$$

$$Revenue = \sum_k P_k G_k \tag{3}$$

$$Production\ cost = \sum_i M_i + \sum_j W_j x_j \tag{4}$$

$$Defect\ cost = \sum_k Salvage_k + Scrap_k \tag{5}$$

$$Salvage_k = \sum_k R\ S_k \tag{6}$$

$$Scrap_k = \sum_k C D_k \tag{7}$$

Constraint

$$1 \le x_j \le 3 \tag{8}$$

The objective function (2) is to maximize the net profit. Equation (3) is revenue determined from product price P and unit sales G of product k. Then, Equation (4) is the production cost summed as machine cost per day M of machine i and labor cost W multiplied with the unit of operator x of process stage j. Equation (5) is the defect cost determined from the number of defects. For instance, when defect parts are sent to rework, the reworked parts are divided into two types-salvaged parts, which can be reshipped and scrapped parts. Equation (6) is total salvage cost determined from rework cost R and salvage units S of product k. Then, Equation (7) is the total scrap cost determined from scrap cost C and scrap units D of product k. The constraint, Equation (8), is the number of operators, which can range from 1 to a maximum of 3.

Table 4 Expressions used in ARENA software for calculations.

Name	Type	ARENA expression
Revenue	Output	175*(NC(Count BV1_FCL) + NC(Count BV1_LCL)) + 135*(NC(Count BV2_FCL) + NC(Count BV2_LCL)) + 97*(NC(Count BV3_FCL) + NC(Count BV3_LCL)) + 45*(NC(Count CN1_FCL) + NC(Count CN1_LCL)) + 40*(NC(Count CN2_FCL)) + 52*(NC(Count WT1_FCL) + NC(Count WT1_LCL)) + 24*(NC(Count WT2_FCL) + NC(Count WT2_LCL))
Production cost	Output	(90*(134.26*MR(SorterMC) + 134.26*MR(SorterMCB) + 115.74*MR(WrapMC) + 92.59*MR(LabelMC))) + (90*400*(MR(AccuOperatorA) + MR(AccuOperatorB) + MR(CheckOperator) + MR(ConsolOperator) + MR(DepalletOperator) + MR(RecordOperator) + MR(RepalletOperator)))
Defect cost	Output	12*(NC(Record SalvageA) + NC(Record SalvageB)) + 25*(NC(Record ScrapA) + NC(Record ScrapB))
Net profit	Output	OVALUE(Revenue) - OVALUE(Production Cost) - OVALUE(Defective Cost)

2.4 Model verification and validation

2.4.1 Model verification

After data were collected over the three month period based on 24 h a day, verification of the model was done by imitating the actual system using real data. The results model outputs were compared with real data.

2.4.2 Model validation

The two datasets of system outputs were compared. The quantity, finished goods determined from the existing model minus comparable numbers from the real system, was determined for model validation. The results are expressed in Table 5:

Table 5 Model validation.

Month	Results of the simulation model	Outputs of the real system	% error
1	Replicate 1: 3598 units Replicate 2: 3611 Replicate 3: 3578	3600 units	0.06-0.61%
2	Replicate 1: 3482 units Replicate 2: 3505 Replicate 3: 3503	3500 units	0.09-0.51%
3	Replicate 1: 3702 units Replicate 2: 3720 Replicate 3: 3718	3700 units	0.05-0.54%

Thus, the existing model can be accurately utilized as a prototype that represents the real system and applied with a margin of error between 0.05% and 0.61%. This performance is much less the maximum allowed margin of error, 5%.

3. Results

After models were developed and simulated with the three months of data based on 24 h per day, they were assessed. The results of simulation and comparison of the existing and proposed models and are detailed in Table 6.

Table 6 Comparison of existing and proposed models.

Criteria	Results		Improvement (%)
	Existing model	Proposed model	
Total finished goods (units)	10,723	13,741	28.2
Work-in-process holding inventory (units)	3,032	8	99.7
Net profit earnings (baht)	693,069.50	980,183.50	41.4
Average total time usage (min)	14,541.62	65.54	99.5

The existing model emulated the actual operations of this case study, showing total finished goods of 10,723 cartons, the work-in-process holding inventory of 3,032 cartons, net profit pf 693,069.50 baht, and average total time of 14,541.62 min per carton during this quarter. Additionally, the proposed model was adjusted using the optimized scenario by allocated two operators for the repalletizing and final recording processes. This resulted in total finished goods of 13,741 cartons, work-in-process holding inventory of 8 cartons, net profit of 980,183.50 baht, and an average total time requirement was 65.54 min per carton over the quarterly period.

4. Discussion

Comparison of improved results to evaluate the existing and proposed models showed an increase in the total finished goods of up to 28.2%. The work-in-process holding inventory decreasing by 99.7%, while the net profit increased by 41.4%, and the average total time required decreasing by 99.5% over the quarter. Computer simulation can be utilized to alleviate bottleneck issues as well as to do optimization and improvement of system operations, according to recent studies. For instance, [8] implemented simulation models in a study of a retail cross-docking center and achieved productive decision-making efforts to improve production performance, while [21] applied simulation models to a study of a general cross-docking facility to maximize service levels and truck utilization, develop feasible lead times for customer order fulfillment, and minimize the number of transport vehicles. In other studies [22] adapted simulation models of a container terminal that reduced investment costs by 18.75%, while [23] utilized simulation models of a container terminal that obtained an operational cost reduction of more than 85%, and [24] leveraged simulation models of a container terminal in which the investment cost decreased using optimal resource allocation.

5. Conclusions

In this case study, we used a simulation technique to pinpoint and eliminate bottlenecks and blockages. These issues delayed operations in a real system. In addition to optimizing and improving production performance in the real operation system, we also developed a simulation model. The proposed model provided the best scenario as

an effective decision tool for resource allocation to obtain maximum profit. The results of the proposed model also demonstrated remarkable improvement in the average total time used, product output, and productivity. In future work, we will apply simulation to analyze operations over a wider scope of general cross-docking by examining more complex logistics and supply chain systems.

6. Acknowledgements

7. References

[1]   Office of the National Economic and Social Development Council. Thailand's logistics report 2019, https://www.nesdc.go.th/; 2020 [Accessed 31 Dec 2020].

[2]   The Geography of Transport Systems. Rail transportation and pipelines, https://transportgeography.org /contents/chapter5/rail-transportation-pipelines/; 2020 [Accessed 30 Dec 2020].

[3]   Siridhara S, Paonoi W, Meeyai S, Ratanavaraha V. Container transport mode choice analysis with a binarylogit model case study: Northeastern Thailand. Eng Appl Sci Res. 2019;46(3):256-256.

[4]   Agustina D, Lee KM, Piplani R. Vehicle scheduling and routing at a cross docking center for food supply chains. Int J Prod Econ. 2014;152:29-41.

[5]   Moghadam SS, Ghomi SMTF, Karimi B. Vehicle routing scheduling problem with cross docking and split deliveries. Comput Chem Eng. 2014;69:98-107.

[6]   Ladier AL, Alpan G. Cross-docking operations: current research versus industry practice. Omega. 2016; 62:145-162.

[7]   Boysen N, Fliedner M. Cross dock scheduling: classification, literature review and research agenda. Omega. 2010;38:413-422.

[8]   Liu Y, Takakuwa S. Enhancing simulation as a decision-making support tool for a cross docking center in a dynamic retail-distribution environment, IEEE Xplore, v1; 2010.https://doi.org/10.1109/WSC.2010.567 8863.

[9]   Delft University of Technology. Cargo consolidation in intermodal container transport, https://repository. tudelft.nl/islandora/object/uuid%3A54333054-a653-4b30-9f83-939cb20579a7/; 2013 [Accessed 15 Jan 2021].

[10]   Pan S, Ballot E, Fontane F. The reduction of greenhouse gas emissions from freight transport by pooling supply chains. Int J Prod Econ. 2013;143(1):86-94.

[11]   Palmer A, Mortimer P, Greening P, Piecyk M, Dadhich P. A cost and CO_2 comparison of using trains and higher capacity trucks when UK FMCG companies collaborate. Transp Res D. 2018;58:94-107.

[12]   Hafezalkotob A, Ketabian H, Rahimi H. Balancing the production line by the simulation and statistics techniques: a case study. Res J Appl Sci Eng Technol. 2014;7:754-763.

[13]   Koltai T, Kalló N. Analysis of the effect of learning on the throughput-time in simple assembly lines. Comput Ind Eng. 2017;111:507-515.

[14]   Jilcha K, Berhan E, Sherif H. Workers and machine performance modeling in manufacturing system using arena simulation. J Comput Sci Syst Biol. 2015;8(4):185-190.

[15]   Chueprasert M, Ongkunaruk P. Productivity improvement based line balancing: a case study of pasteurized milk manufacturer. Int Food Res J. 2015;22:2313-2317.

[16]   Kusoncum C, Sethanan K, Putri EP, Neungmacha W. Simulation-based approaches for processes improvement of a sugar mill yard management system: a case study of the sugar industry in the central region of Thailand. Eng Appl Sci Res. 2018;45(4):320-331.

[17]   Aliyu AI, Sulaiman TA, Yusuf A. Modeling and simulation analysis of health care appointment system using ARENA. Int J Sci Appl Inf Technol. 2015;4:1-7.

[18]   Calderón-Andrade R, Hernández-Gress ES, Montufar Benítez MA. Productivity improvement through reengineering and simulation: a case study in a footwear-industry, MDPI AG, v1;2020. https://doi.org/ 10.3390 /app10165590.

[19]   Kotachi M, Rabadi G, Obeid MF. Simulation modeling and analysis of complex port operations with multimodal transportation. Procedia Comput Sci. 2013;20:229-234.

[20]   Alharkan I, Saleh M, Ghaleb M, Farhan A, Badwelan A. Simulation-Based Optimization of a Two-Echelon Continuous Review Inventory Model with Lot Size-Dependent Lead Time, MDPI AG, v1;2020. https://doi.org/10.3390/pr8091014.

[21]   Navin M, Rajan N. Simulation modeling and analysis of cross dock implementation in distribution network. Int J Sci Res. 2016;5(12):1520-1523.

[22]   Lin J, Gao B, Zhang C. Simulation-based investment planning for humen port. Simul Model Pract Th. 2014;40:161-175.

[23]   Cimpeanu R, Devine MT, O'Brien C. A simulation model for the management and expansion of extended port terminal operations. Transp Res E Logist Transp Rev. 2017;98:105-131.

[24]   Wan J, Meng Q, Wang W. Optimization for container Handling equipments allocation based on ARENA, IEEE Xplore, v1;2010. https://doi.org/10.1109/ICIEEM.2010.5645982.