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The Design of Handling Process in Post-
Production Stage for Precast Concrete Manufacturing

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A Thesis Submitted in Partial Fulfillment of the Requirements
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ในปัจจุบันอุตสาหกรรมก่อสร้างในประเทศไทยได้มีการเปลี่ยนรูปแบบการก่อสร้างมาใช้ในระบบชิ้นส่วนคอนกรีตสำเร็จรูปกันมากขึ้นเนื่องจากมีการเปลี่ยนแปลงต่างๆ โดยส่วนใหญ่โรงงานจะใช้ระบบกึ่งอัติโนมัติและจะให้ความสำคัญกับประสิทธิภาพของฝ่ายผลิต อย่างไรก็ตามโรงงานมักประสบปัญหาเรื่องประสิทธิภาพในกระบวนการหลังการผลิตซึ่งเกี่ยวข้องกับการขนถ่ายสินค้าเป็นหลัก ตั้งแต่การขนถ่ายสินค้าจากโต๊ะผลิตไปยังหน่วยตรวจสอบคุณภาพ ไปยังที่จัดเก็บ และขนถ่ายขึ้นรถบรรทุก ดังนั้นวัตถุประสงค์ของงานวิทยานิพนธ์นี้คือ เพื่อออกแบบขั้นตอนการขนถ่ายสินค้าหลังขั้นตอนการผลิตสำหรับโรงงานผลิตชิ้นส่วนคอนกรีตสำเร็จรูปเพื่อรองรับความต้องการของตลาดในรูปแบบต่างๆ ในการศึกษาขั้นแรกคือการจัดทำขั้นตอนการทำงาน โดยระบุที่ความสูญเสียและต้นเหตุของความสูญเสียนั้นๆ โดยใช้หลัก 7 Wastes of Lean จากนั้นใช้ Little’s Raw เพื่อหาจำนวนสินค้าคงคลัง และทำการประมาณต้นทุนการจัดเก็บทั้งหมด อย่างไรก็ตามเมื่อตลาดมีความต้องการสินค้าสูงขึ้น ปัญหาในการขนถ่ายสินค้าได้ปรากฏชัดเจนและใช้เวลาในการขนถ่ายสินค้าเพิ่มขึ้น 674% จากการทำงานเดิม เนื่องจาก ความแออัดในพื้นที่จัดเก็บ เกิดการขนถ่ายที่ไม่จำเป็น และ ชั้นจัดเก็บ A-Frame มีจำนวนไม่เพียงพอ ซึ่งปัญหาเหล่านี้ได้สะท้อนไปยังการเพิ่มขึ้นของต้นทุนการจัดเก็บ อย่างไรก็ตามในการหาวิธีแก้ปัญหานั้น แบบจำลองระบบการขนถ่ายสินค้าที่ตรวจสอบกับระบบปัจจุบันได้ถูกนำมาใช้ในการออกแบบการขนถ่ายสินค้าในรูปแบบกรณีต่างๆ 17 รูปแบบ เช่น ปรับเปลี่ยนลำดับการจัดเก็บ หรือชนิดของชั้นจัดเก็บ เป็นต้น จากศึกษาพบว่าการใช้ชั้นวางชนิด A-Frame จำนวน 40 อัน และปรับปรุงลำดับการจัดเก็บนั้นให้ผลเชิงปฏิบัติการและการลงทุนที่ดีที่สุด ซึ่งสามารถลดต้นทุนการจัดเก็บได้ 14.84% เพิ่มผลผลิตต่อวันได้ 5.52% จากการทำงานปัจจุบัน และใช้เวลาคืนทุน 3.67 ปี และจากการตาดการณ์ความต้องการของตลาดระดับต่างๆ พบว่า ในการลงทุนใช้ชั้นจัดเก็บชนิด A-Frame จำนวนอีก 23 อัน ใช้เวลาคืนทุน 2.92, 4.00 และ 4.92 ปี ในสัดส่วนความต้องการของตลาดสูงต่อต่ำรายปี 65ต่อ35, 50ต่อ50 และ 35ต่อ65 ตามลำดับ อย่างไรก็ตามหากเปลี่ยนไปลงทุนชั้นจัดเก็บแบบเสียบระยะคืนทุนจะเพิ่มขึ้นเฉลี่ยเพียง 3.50% จากชั้นวางแบบ A-Frame เนื่องจากสามารถช่วยลดต้นทุนของหน้างานได้

ภาควิชา	วิศวกรรมอุตสาหการ	ลายมือชื่อนิสิต	....
สาขาวิชา	วิศวกรรมอุตสาหการ	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
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CHALIT UDOMPORNWATTANA: The Design of Handling Process in Post-Production Stage for Precast Concrete Manufacturing. ADVISOR: ASST. PROF. SEERONK PRICHANONT, Ph.D., 71 pp.

Recently, Thailand's construction industry has turned its attention to the precast concrete systems to improve its efficiency. Most of precast concrete factories focus on the production efficiency. However, many cases of efficiency problem occur in handling processes in post-production stage until handling wall panel onto delivery truck, as a bottleneck of the system. The purpose of this study is, therefore, to design handling process in post-production stage to efficiently satisfy production's throughput under fluctuating market demand. Firstly, 7 Wastes of Lean, and Little's Law are used to illustrate existing workflow and wastes, and estimate lead time and work-in-process (WIP) inventory which are turned to total holding cost. The study shows that sharp raising in throughput increases lead time significantly by 674% from regular workflow because of the congestion, double handling, and insufficient wall panel storage racks which are called A-Frame rack that directly raise total holding cost. To investigate solutions, for the first part (scenario 1-8), the model is used to experiment in reassigning of stock location, adjusting number of A-Frames, and changing to use vertical slot racks under current demand. Then, the model results suggest that 40 moveable A-Frame with improved sequence of stock location is the best practice. It reduces holding cost by 14.84%, and increases throughput by 5.52% from current system with payback period of 3.67 years. For the second part (scenario 9-17), the best practice is examined under different demand pattern. With additional 23 moveable A-Frame racks cases requires payback period of 2.92, 4.00, and 4.92 years under annual high to low demand ratio at 65:35, 50:50, and 35:65, respectively.

Department:	Industrial Engineering	Student's Signature	....
Field of Study:	Industrial Engineering	Advisor's Signature	....
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Secondly, I would like to thank precast concrete factory's owner that allow me to use his factory as a case study. In addition, I would like to thank factory's managers, especially manager of inventory and logistic department. They provided a useful information and data in this study, and also assigned team to collect further necessary data for the simulation model, and study.

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CONTENTS

Page

Page

TABLE OF FIGURES

Page

TABLE OF TABLES

Page

Page

APPENDIX

Page

1. Introduction

1.1. Background of the Research

In recent years, there are many evidences that support the advantages of adopting precast concrete system. Precast concrete systems have been developed and widely used in the western countries. The systems have been used in construction types, such as office building, bridge segments, and residential building. In comparison between precast concrete construction system and conventional (cast-in-place) construction system, precast concrete construction system provides several benefits of construction effectiveness, high levels of quality control, saving of construction time, minimizing labor's skills requirements, reduced manpower on site, and saving in formwork requirements. Furthermore, trend of precast concrete system is coming in Asia, such as China, Thailand, and Vietnam which recorded as a key driven of industrialization and economic growth. (Elematic, 2010)

In these days, in Thailand's construction industry, several factors, such a raised in minimum wage and higher quality concerned, drive construction companies gradually change from conventional construction system to precast concrete system. Consequently, number of precast concrete factory is increased (Waroonkun, T & Koojaroenpaisan, R. 2011), and owned by both real estate developer companies to serve themselves as their vertical integration strategy, and construction companies to serve market needs directly. Real estate developer is one of the key drivers of increasing number of factory because precast concrete products are used as necessary material to build their product, houses and condominium. Consequently, because number of factory is growing and construction seems to be more industrialize. Hence, manufacturing managerial skills becomes more important and relevant to complete a well operation in construction.

Basically, precast concrete products consist of various categories. Such as, for non-structural precast concrete, paving block, concrete tile, roofing and garden products, and, for structural product, precast concrete beam, column, and wall.

In Thailand, due to raise of minimum worker wage, construction works which require high man power are tend to be reduced and eliminated, such as masonry work. Hence, masonry wall which use brick and mortar that consume high manpower and tends to increase total construction cost and time is replaced with precast concrete wall panel which is more neatness, consume lower manpower, less total construction time, and cost. Thus, trend of using precast concrete wall panel is raising and became popular rapidly in both construction and real estate developer industry in Thailand, nowadays.

Furthermore, most of precast concrete consumption is relevant to construction industry's characteristic, then market demand is seasonal dynamic demand pattern (Marasini, R., Dawood, N. N. et al., 2001). In several countries, demand is peak in summer, but low in winter. For Thailand, demand is peak in summer and winter, but low in rainy season. On the other hand, in perspective of business, profit is one of key performance index to measure business's success. So companies aim to increase in sales and satisfy their customers, while reducing their expenses, or cost. As a manufacturing, improving in operating's efficiency and effectiveness is a keys to reduce their unnecessary costs and expenses, and goods are still delivered to customer within schedule. To serving business's goal and dynamic market demand, the biggest challenge for precast concrete manufacturer is to serve demand in peak season on schedule efficiently.

In general, to establish precast concrete plant, factory size and types are varied according to local demand and market. Machinery companies, which mostly are western companies, would suggest machinery, equipment, and plant layout that precast manufacturer requested. According figure 1, it shows common stations in production line with integrated management software that would provide to precast manufacturer. The management software provides benefit of monitoring performance in production line, such as recording process time in each station. Mainly, the production capacity is calculated based on performance of production machinery specification, and number of production line. However, due to it requires high initial investment in that machinery, equipment, system, and software. Level of automation, number of equipment, and plant size would be invested based on budget of owner.

At same production capacity, lower investment in plant and equipment tends to increase level of management when factory is operated.

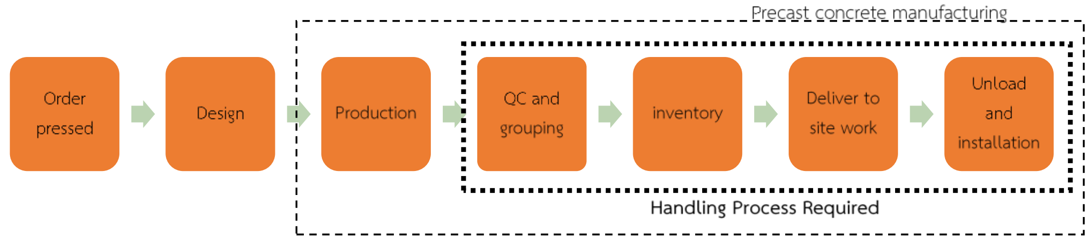

Figure 1 Common Workflow in Precast Concrete Manufacturing

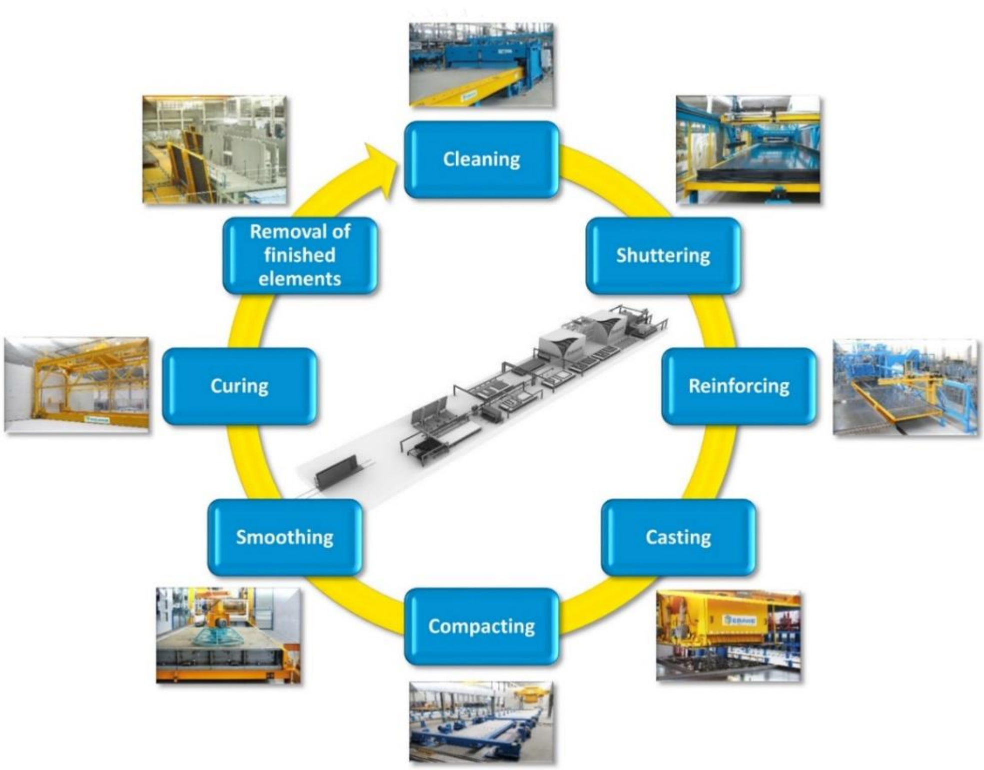

Figure 2 Workflow in precast concrete production process (wall panel) (Ebawe, 2016)

According Figure 1, it shows that general workflow in each precast concrete manufacturing which produces made-to-order concrete components, such as beam, column, floor slab, and wall panel. When purchase order is pressed, building drawing would be sent to design department to design, divide into concrete structure elements and draft shop drawings. After that, all shop drawings would be sent to producing in production line which is clearly illustrated in Figure 2. After finish producing, finished goods would be handled by crane to check their quality (QC), and grouping according to sequence of installation, then transfer to stock in stockyard. Inventory area or stockyard could be indoor or outdoor area as well as handling method that might handle product piece by piece, or a rack that contains several pieces of product. On delivery date, 10-wheeler truck or semi-trailer truck (18-wheeler truck) would come to pick up those products and deliver to site work. When truck arrived site-work, products would be handled to stockyard on site work and installed by mobile crane. Furthermore, installation of precast components has to be aligned construction project schedule, production schedule, inventory, and delivering efficiently. Consequently, operating precast concrete factory create challenges issues for manufacturers to manage their factory in efficiency way. Precast concrete manufacturing requires high level of management and is heavy. Hence, heavy equipment, crane, is needed and it also consumes time to move from location A to B.

There are several studies that provide solution to tackle problematic issues in several types of precast concrete factory by using various approaches by adapting Lean philosophies, waste elimination, and simulation as investigating tools. But each factory would has different unique problem situation that require different combination tools to conduct solutions to improve its efficiency level. In this study, a precast concrete manufacture with semi-automatic continuous production line in Thailand is used as a case study to clearly identify and illustrate problem and solutions in real situation.

1.2. Company Background and Existing Situation

The precast concrete element manufacturer established in 2011 and located in suburban area of Bangkok. The company, as a manufacturer, produces various types of precast concrete products such as precast wall panel, slab, stair, column, and beam to serve local market majorly for real estate developer companies. Its products are mostly used as concrete structure of building in housing estate project which includes detached house, townhome, and commercial building which have quite similar building model in each project.

1.1.1. Overall Workflow

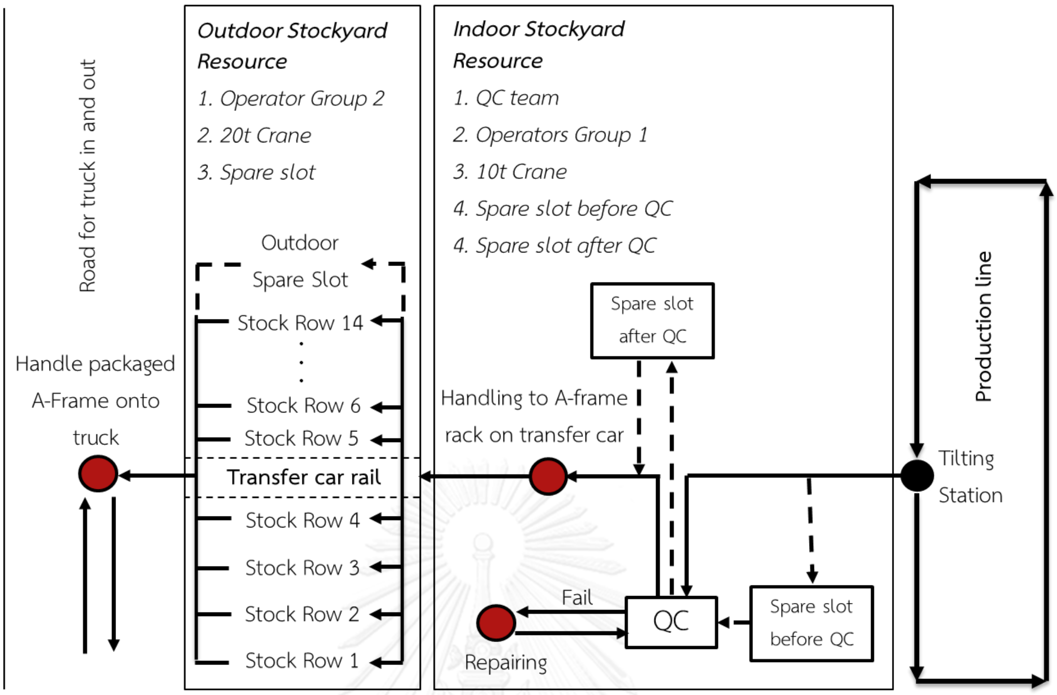

Figure 3 Workflow in Precast Factory (From Production Line to Stockyard)

Typically, in operation part, according to Figure 3, the company has been invested in continuous semi-automated production line system for producing wall panel and slab According to that production line, production capacity of wall panel and slab is designed at 300 sq.m./day with integrated software providing real time monitor in each station on PC screen in office. After products produced, in post-production process, it has 10-ton crane used to handle finished products from tilting table station to qualify in QC station. Qualified wall panels would be handled to A-Frame rack on transfer car by stacking from inside to outside on both side of rack. With this process, product would be sorted and group as a package in accordance with sequence of installation and difficulty limitation. However, wall panel with significant large opening must be located outside to prevent damage and crack during handling and transferring process. However, activities in indoor stockyard are finished by a 10-ton crane and operator group 1. Then full packaged A-Frame rack would be transfer to outdoor stockyard area. 20-tons crane would be used to handle full A-Frame to stock in outdoor stockyard area. On delivery day, packaged A-Frame is handled on to

10-wheeler truck by 20-ton crane and operator group 2. Shortly, after finished production process, wall panel has to be transferred to several stations and places until loading onto truck. Hence, handling process is a major process that involve along post-production process until installation process.

1.1.2. Monthly Production Record

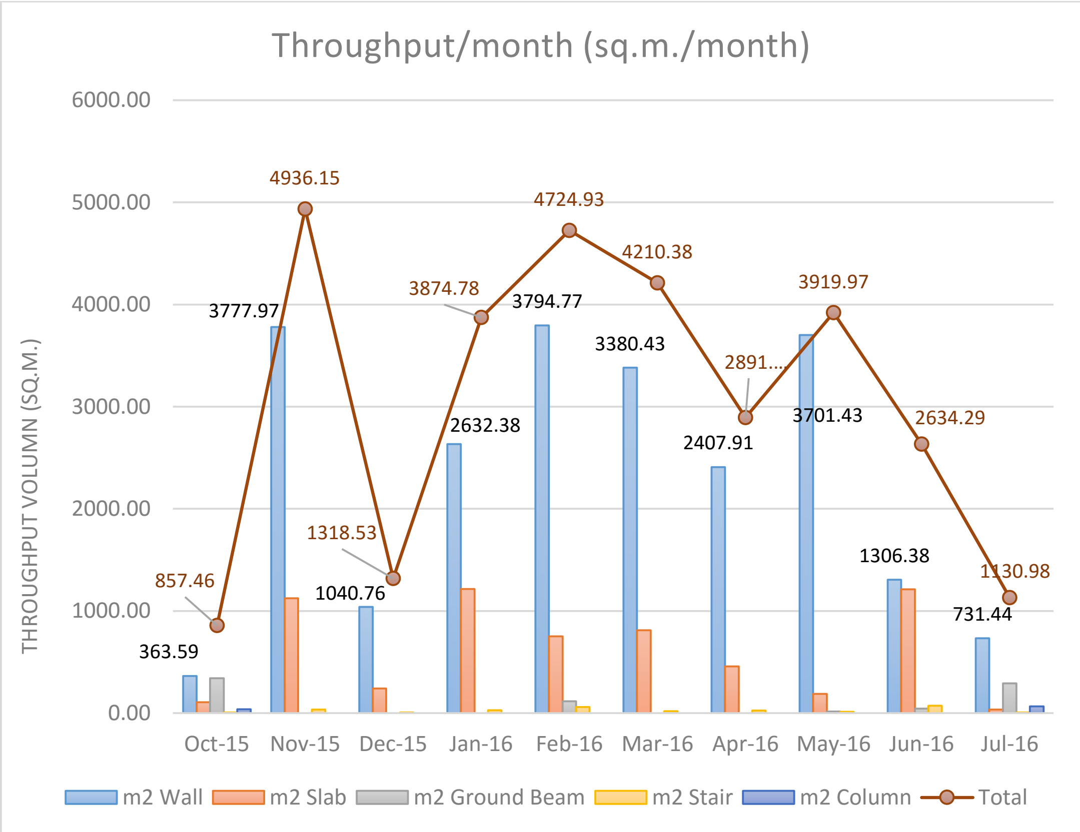

Figure 4 Monthly Production

As designed production line capacity is 300 sq.m./day, according to monthly production in Figure 4, it shows that precast wall panel is the product which the factory produces at the largest proportion of total products as its main product. With this data, it distinctly shows trend of seasonal dynamic demand (Ramesh Marasini R. & Dawood N N. & Hobbs B. 2001) which record low demand in rainy season, and long holiday. During November to May, this period could be defined as high season period except December, and April due to New Year and Thai tradition holiday which takes 2-3 weeks off in construction industry. The highest production output is recorded in February.

Refer to table of monthly production in Table 1, it shows that, in high season period, wall panel is produced at average 149.55 sq.m./day (80.46% of total production). In November, it is recorded as a peak month on average of 171.73 sq.m./day (76.54% of total production) with peak daily wall production record at 263.51 sq.m.

Table 1 Monthly Wall Panel Production

Month	sq.m.				
	Total	Total Wall	Total Wall / Total production (%)	Average wall (sq.m./day)	Peak wall(sq.m./day)
Oct-15	857.46	363.59	42.40%	15.15	123.90
Nov-15	4936.15	3777.97	76.54%	171.73	263.51
Dec-15	1318.53	1040.76	78.93%	61.22	160.40
Jan-16	3874.78	2632.38	67.94%	119.65	286.47
Feb-16	4724.93	3794.77	80.31%	158.12	249.59
Mar-16	4210.38	3380.43	80.29%	130.02	258.30
Apr-16	2891.81	2407.91	83.27%	120.40	251.71
May-16	3919.97	3701.43	94.42%	168.25	281.96
Jun-16	2634.29	1306.38	49.59%	52.26	181.38
Jul-16	1130.98	731.44	64.67%	30.48	129.76
Aug-16	2276.83	1412.51	62.04%	61.41	153.51
Sep-16	1520.70	839.93	55.23%	35.00	146.98

1.1.3. In detail of internal Working Resources, and Stock Location of Handling Process in Post-Production Stage

In handling process in post-production stage which starts from tilting station to erecting, areas are separated into 2 main areas, which consists of indoor stockyard, outdoor stockyard, and on-site.

Table 2 Working Resource

No	Resource	Unit of resource avaliable
Indoor stockyard area		
1	Operator Group 1	1
2	Crane 10 ton	1
3	QC team	1
Outdoor stockyard area		
4	Transferring car	1
5	Operator Group 2	1
6	Crane 20 ton	1

According to Table 2, it shows working resource of handling process in post-production stage, includes indoor stockyard area, and outdoor stockyard. Firstly, for Indoor stockyard area, operation group 1 is responsible for handling wall panels from production (tilting table station) to QC working area and from QC working area to outdoor stockyard as a packaged rack on transferring car in normal case by using 10 tons crane. Secondly, for outdoor area, operation group 2 is responsible for receiving wall panel from indoor stockyard transferred on transferring car to stock in appropriate stock area waiting for truck on delivery day. Then, A-Frame rack with wall panels would be handled onto truck to deliver to construction site on committed date.

Table 3 List of stock location and its capacity

No	Stock location Resource	Unit	Capacity (sq.m.)	Inventory day (day)
1	Moveable A-Frame rack	17	1020.00	5.94
Indoor stockyard				
2	Indoor QC slot	24	151.55	0.68
3	Indoor QC spare slot	30	189.43	0.83
Outdoor stockyard				
4	Outdoor spare slot	350	2210.06	11.74

According to Table 3, it shows all types of stock location that related to handling process with its capacity. Moveable A-Frame rack is mainly used to transfer products as a packaged wall panels after quality checked to outdoor stockyard, and from outdoor stockyard to site work. It consists of 8-10 pcs, 50 – 60 sq.m. on average, of wall panels accordance with erection plan. In this case study, this type of rack is mainly used both inside factory and delivery to site work. The advantages of using A-Frame rack is that it required lower initial investment than another type of rack. But, the disadvantages are that wall panels are dependent to each other because they are stacked from inside to outside on both sides, as shown in Figure 5. Moreover, wall panel with large opening has to be located on outside layer which tends to be carried 2-4 wall panels with opening per rack.

Figure 5 A-Frame racks in outdoor stockyard

However, when A-Frame rack is unavailable, and wall panels are transferred to outdoor stockyard, outdoor spare slot is directly used to stock finished wall panels waiting for returning of A-Frame rack from site work, and to prevent obstructing of finished wall panels' outflow from indoor stockyard.

Indoor QC slot is both stock area and working space after tilting station for supporting QC worker to check and examining before handling onto A-Frame rack on transferring car. This is important working area that has to be balanced flow closely because too high inventory level might interrupt QC work.

In case of QC slot is full that would interrupt QC work and tend to reduce QC output, excess wall panel would be handled to QC spare slot waiting for QC slot free. Furthermore, in case of outdoor crane is unavailable to handle wall panels out of transferring car and QC slot is full, excess finished wall panels would be also handled to QC spare slot to prevent reduction in QC station's output.

Briefly, normally, moveable A-Frame rack is used to transfer, and stock finished wall panels from indoor to outdoor stockyard, then when moveable A-Frame is fully utilized, finished wall panels would be transferred to outdoor spare slot waiting for free moveable A-Frame. However, QC spare slot, and outdoor spare slot are used in extreme case to balance flow from indoor inventory to outdoor inventory, and prevent obstructing in system.

1.1.4. Current Situation in High Demand Season of Handling Process in Post-Production Stage

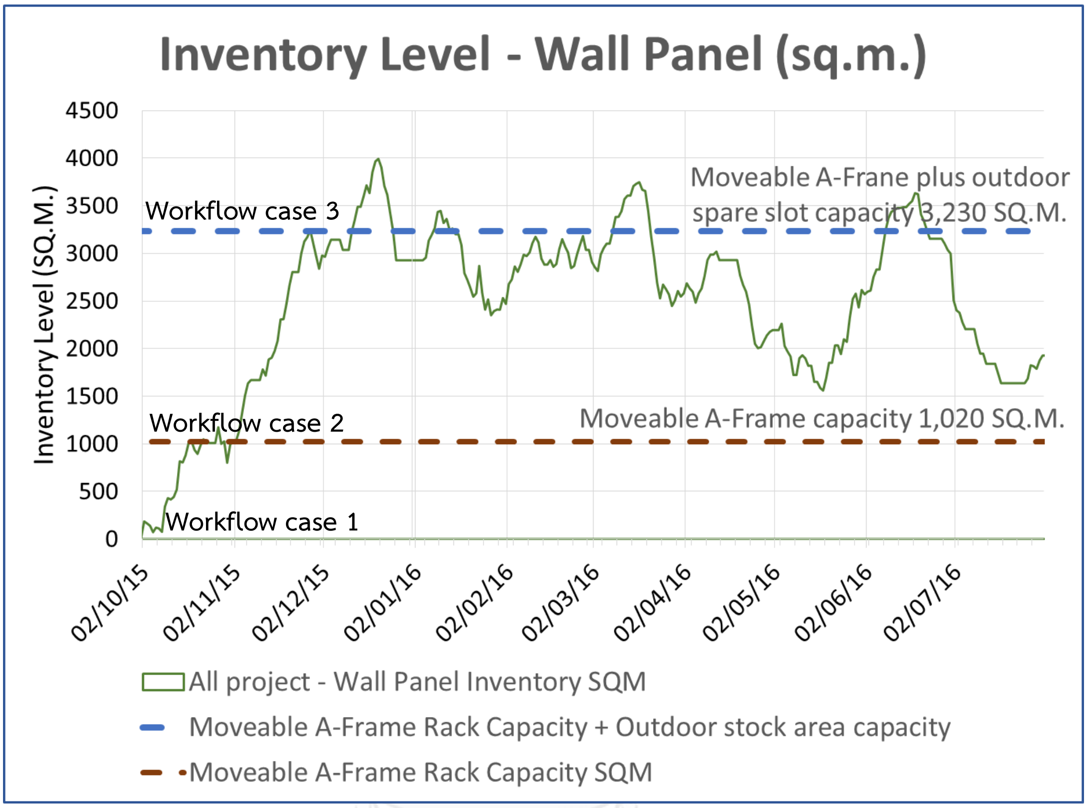

Figure 6 wall panel inventory level with moveable A-Frame and outdoor spare slot capacity and 3 possible cases of workflow

According to Figure 4, it shows that wall panel production is the largest proportion of total production transferring into inventory area, before deliver to erection on sites. Moreover, it reflects that high season period is started from November to May, except December and April. December, April, June and July are recorded as low season period because of raining season and long holiday as nature of construction industry. In additional, most of finished goods would not be stocked on site, but in its factory to prevent risk of damage and double handling. Hence, the manufacture has to manage their stockyard to support both sides of production and site work, appropriately. For wall inventory, it generally counts as summation of area (sq.m.) of each wall panel received as input minus summation of area (sq.m.) of each wall panel delivered as output. However, unit of pieces (pcs.) is generally also used for counting and averaging in precast concrete products.

According to Figure 6, it shows inventory level with critical capacity of moveable A-Frame and outdoor spare slot (dashed line). Wall panel inventory level fluctuated in range of 1588.94 sq.m. as the lowest, and 3731.56 sq.m as the highest. It clearly consists of 4 peak points in this period due to uncontrollable external factors.

Because there are 2 main storage areas for stocking wall panels before deliver to site work. When inventory level is increased beyond each critical capacity (dashed line), it affects changing in handling process and workflow of post-production stage. Because of changing in workflow to support excess capacity and balance flow, it might increase waste in the system, such as increasing in process, double handling, and risk of damage. However, possible workflow could be divided into 3 cases.

According to Figure 7, 8, and 9, there are 3 possible cases of workflow depending on level of inventory in post-production stage.

Workflow Case 1: Low inventory level with minimal processes on both indoor, and outdoor stockyard.

For workflow case 1 (inventory level under 1,020 sq.m.), refer to Figure 7, it contains minimal number of process in comparison to other cases. It is because free moveable and working space in both indoor and outdoor stockyard are sufficient for the system. Definitely, at constant throughput, lead time is recorded at the lowest, compared to other cases.

Workflow Case 2: Moderate inventory level with minimal processes on indoor, but extended processes on outdoor stockyard.

For workflow case 2 (inventory level between 1,020 sq.m. and 3,230 sq.m.), moveable A-Frame racks are fully utilized. When wall panels are transferred into outdoor stockyard, number of process and handling would be increased to balance and maintain throughput of the system. Surely, lead time would be increased with additional activities and waiting time.

Workflow Case 3: High inventory level with extended processes on both indoor, and outdoor stockyard.

For workflow in case 3 (inventory level beyond 3,230 sq.m.), moveable A-Frame racks outdoor spare slot are fully utilized, then those finished wall panel would be held in indoor stockyard waiting for availability of moveable A-Frame rack, or outdoor spare slots. This causes additional processes and handling in indoor stockyard to maintain and balance throughput of the system. Consequently, lead time and waiting time would be clearly increased and higher than other cases.

Indoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P
Activity	Handle product from tilting table to QC station	Wait for QC	QC checking and examining	Decide consequence of wall panel on rack	Handle, and arrange product onto A-Frame rack on transfer car
Time (minute/piece)	5.42	10.32	14.89	12.11	5.71

(50% of total input required examining)

Outdoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P	P
Activity	Move transferring car to outdoor area	Wait for Crane 20t and Operator Gr. 2	Handle arranged A-Frame rack to stockyard	Wait for truck that align with erection plan	Handle arranged A-Frame rack onto truck	Full-loaded truck travel to site
Time (minute/piece)						
Time (minute/rack)	1.00	8.53	7.29	108.93	8.73	Depend on location

Figure 7 Workflow of Handling Process in Case 1

Indoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P
Activity	Handle product from tilting table to QC station	Wait for QC	QC checking and examining	Decide consequence of wall panel on rack	Handle, and arrange product onto A-Frame rack on transfer car
Time (minute/piece)	5.42	10.32	14.89	12.11	5.71

(50% of total input required examining)

Outdoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P	W	P	P
Activity	Move transferring car to outdoor area	Wait for Crane 20t and Operator Gr. 2	Handle each product to slot rack on stockyard	Wait for free A-Frame rack	Handle and arrange product onto free A-Frame rack	Wait for truck that align with erection plan	Handle arranged A-Frame rack onto truck	Full-loaded truck travel to site
Time (minute/piece)								
Time (minute/rack)	1.00	8.53	50.38	720.00	143.14	108.93	8.73	Depend on location

Figure 8 Workflow of Handling Process in Case 2

Indoor Stockyard

	In case: QC station is full of WIP products and new product is coming				In case: QC station is full of finished products and new product is coming		
Type of Work (P=Processing, W = Waiting)	P	P	W	P	P	W	P
Activity	Handle product from tilting table to free slot	Handle to QC station	Wait for QC	QC checking and examining	Handle product to free slot	Wait for proper queue on A-Frame rack.	Handle unarranged product onto A-Frame rack on transfer car
Time (minute/piece)	5.41	5.42	10.32	14.89	5.41	12.11	5.71

(50% of total input required examining)

Outdoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P	W	P	P
Activity	Move transferring car to outdoor area	Wait for Crane 20t and Operator Gr. 2	Handle each product to slot rack on stockyard	Wait for free A-Frame rack	Handle and arrange product onto free A-Frame rack	Wait for truck that align with erection plan	Handle arranged A-Frame rack onto truck	Full-loaded truck travel to site
Time (minute/piece)								
Time (minute/rack)	1.00	8.53	50.38	720.00	143.14	108.93	8.73	Depend on location

Figure 9 Workflow of Handling Process in Case 3

2. Problem Statement

The system analysis of the current situation suggested that process in post-production stage is the bottle-neck of overall system. In detail, overall system consists of 3 main stages which are production, post-production, and delivery stage. Firstly, production throughput is able to adjust its capacity up to 300 sq.m./day for production stage. Secondly, for delivery stage, the company hires external logistic firms. Hence, delivery capacity is able to be increased to support production throughput up to 300 sq.m./day. Thirdly, on the other hand, increase throughput of post-production stage, aligning with overall system's throughput, causes additional handling processes that affect total holding cost. Hence, to smooth the overall system so that post-production stage's throughput would be increased, the handling process has to be studied, and wastes are eliminated to reduce its total holding cost.

2.1. Current Wastes of Handling Process in Post-Production Stage

Table 4 Reducible and Eliminable Wastes of 3 Workflow Cases

No.	Name	Workflow Case	Location	Root cause
1	Decide consequence of wall panel on rack	1,2,3	Indoor stockyard	Using of A-frame rack
2	Handle each product to slot rack on outdoor stockyard	2,3	Outdoor stockyard	Lacking of free moveable Rack
3	Wait for free A-Frame rack	2,3	Outdoor stockyard	Lacking of free moveable Rack
4	Double handle and arrange product onto free A-Frame rack on outdoor stockyard	2,3	Outdoor stockyard	Lacking of free moveable Rack
5	Handle product from tilting table to indoor spare slot	3	Indoor stockyard	Lacking of free moveable Rack and fully utilized of outdoor spare slot
6	Handle product to indoor sprare slot waiting for availablity of outdoor area	3	Indoor stockyard	Lacking of free moveable Rack and fully utilized of outdoor spare slot

After the investigation handling process has been carried out, wastes can be identified in all 3 workflow cases. However, this study aims to consider 5 from 7 types of wastes, which are waste of transportation, inventory, motion, waiting, and over-processing. The waste of overproduction and defects are not included in the scope of study because those are not related to post-production stage.

According to Table 4, it shows all reducible and eliminable wastes in handling process in all 3 cases of workflow with its location and root cause. As using 7 Wastes Framework, this study considers 5 of 7 wastes. Waste of defect and overproduction are excluded because they are not related to the scope and are of study. However, wastes are discussed individually, as follow.

1.) Waste of deciding consequence of wall panel on rack

It categorized as waste of waiting that requires additional waiting time because of limitation of difficulty. The root cause is using an A-Frame and the waste occurs in all 3 workflow cases. It requires additional 4.87 minute per piece in comparison to using vertical slot rack that eliminated this waiting time.

2.) Waste of handling each product to slot rack on outdoor stockyard

It categorized as waste of over processing that increase number of process to manage individual wall panel. It is due to lacking of free moveable A-Frame. The waste occurs in workflow case 2, and 3. It requires additional 50.38 minute per rack.

3.) Waste of waiting for free A-Frame on outdoor stockyard.

It categorized as waste of waiting that increases additional waiting time of 720 minutes for returning of moveable A-Frame. It occurs in workflow case 2, and 3.

4.) Waste of double handling and arranging product onto free A-Frame rack on outdoor stockyard.

It categorized as waste of over processing that increase number of process on outdoor stockyard to handle wall panel individually, and arrange onto moveable A-Frame rack. It is due to lacking of free moveable A-Frame. The waste occurs in workflow case 2, and 3. It requires additional 143.14 minute per rack.

5.) Waste of handling product from tilting table to indoor spare slot before quality checking.

It categorized as waste of over processing that increase number of process on indoor stockyard to handle wall panel to manage excess inventory in buffer area before transferring to quality checking. The root causes are lacking of moveable free A-Frame, and outdoor stockyard area. However, the waste occurs in workflow case 3. It requires additional 5.41 minute per piece.

6.) Waste of handling product from quality control station to indoor spare slot after quality checking.

It categorized as waste of over processing that increase number of process on indoor stockyard to handle wall panel to manage excess inventory in buffer area before transferring and arranging onto transfer car. The root causes are lacking of moveable free A-Frame, and fully utilized of outdoor spare slot. However, the waste occurs in workflow case 3. It requires additional 5.41 minute per piece.

After analyzed wastes with 7 Wastes framework, 3 root causes of wastes in handling processes in post-production stage are using of A-frame rack, lacking of free moveable A-Frame, and fully utilized of outdoor spare slot, as shown in Table 4. 3 Hence, these wastes cause increasing in lead time, and work-in-process inventory (WIP) which directly relate to the increases in holding cost.

2.2. Increasing in Lead Time of Handling Process in Post-Production Stage

Table 5 Lead time comparison

	WF Case 1	WF Case 2		WF Case 3	
Category	Lead Time / Rack (min)	Lead Time / Rack (min)	%Change from WF Case 1	Lead Time / Rack (min)	%Change from WF Case 1
Indoor activity	328.08	328.08	0%	414.58	26%
Outdoor activity	134.48	1040.72	674%	1040.72	674%
Total	462.57	1368.80	Total	1455.29	

According to Table 5, it shows that when work flow case is changed from 1 to 2, and 3 to maintain throughput of handling process. Lead time tend to be increased because of increasing in time, processes, and inventory which are defined as wastes. Hence, in comparison to workflow case2, lead time of outdoor area's activities is increased 674% mainly because of over-processing, double handling, handling wall panel individually, instead of handling whole rack, and waiting for returning of moveable A-Frame rack. This might increase unnecessary work to outdoor area's workers and extend to work overtime. Furthermore, when it turns to workflow case 3, lead time of indoor area's activities is increased up to 26%, compared to workflow case 1, because wall panels have to be stock in indoor area waiting for availability of outdoor stockyard, so it might increase unnecessary work to indoor area's workers and extend to work overtime.

2.3. Increasing in Work-In-Process Inventory (WIP) of Handling Process in Post-Production Stage

Table 6 Inventory and Throughput Boundary of Each Workflow Case

Workflow Case 1	
I_limit 1 (sq.m.)	**1,020.00**
Lead Time (min/rack)	298.52
R_limit 1 (sq.m./day)	43.92
Workflow Case 2	
I_limit 2 (sq.m.)	**3,230.00**
Lead Time (min/rack)	1,204.76
R_limit 2 (sq.m./day)	128.61
Workflow Case 3	
I_limit 3 (sq.m.)	**3,419.49**
Lead Time (min/rack)	1,248.01
R_limit 3 (sq.m./day)	135.67

In this study, inventory level is considered on work-in-process inventory (WIP) which calculated by Little's Law formula (I = RT) because WIP is the minimum inventory level to maintain each level of throughput (R) in the system. Hence adjusting system's throughput (R) would affected level of inventory (I) and change patterns of workflow from case 1 to 2, and 3, consequently, which tend to increase in lead time (T), and holding cost.

However, lead time of customer requesting products is not considered in this study because it is defined as uncontrollable external factor which would be calculated and used the average value of 22.60 days in study period.

According to of 22.60 days in study period., it shows boundary of throughput (R) at inventory's capacity at each workflow case. For workflow case 1 with inventory limit at 1,020 sq.m., it could be held maximum throughput at 43.92 sq.m./day, while throughput between 43.92 and 128.61 sq.m./day would change workflow of handling process from case 1 to 2 with inventory and throughput limit at 3,230 sq.m., and 128.61 sq.m./day, consequently, because moveable A-Frames are fully utilized, but products are stocked in outdoor spare slot. Furthermore, when outdoor spare slot are full, handling process would turn to use workflow case 3 to stock product in indoor spare slot at maximum throughput level of 135.67sq.m./day., and inventory limit at 3,419.49 sq.m. Beyond throughput level of 135.67 sq.m./day, system tends to be broken down, and production rate tend to be slow down and obstructed due to fully utilized of both outdoor, and indoor stockyard.

2.4. Assumption for Estimating Financial Impact

To balance overall throughput at higher demand level, it requires to shift workflow case of handling processes in post-production stage from 1 to 2, and 3, respectively. Consequently, lead time, and work in process inventory (WIP) are increased, as wastes in the system, which affects to total holding cost per day. Total holding cost consists of opportunity cost of holding inventory, stockyard leasing cost, labor cost, head office cost, etc. However, cost calculation is based on assumption, as follow;

1.) Production throughput	149.55	sq.m./day
2.) Average wall panel area/piece	6.34	sq.m./pc.
3.) Working day per month	26	days
4.) Precast concrete wall panel price	1,000	THB/sq.m.
5.) Precast concrete wall panel profit margin	15.00	%
6.) Outdoor stockyard leasing cost	100	THB/sq.m.
7.) Indoor stockyard leasing cost	120	THB/sq.m.

8.) Required inventory area for excess wall panel	0.80	sq.m.
9.) Precast concrete wall panel cost	850	THB/sq.m.
10.) Weight average cost of capital	10.33	%
11.) Monthly revenue	5,054,790	THB./month
12.) Head office cost	50,000	THB./month
13.) Labor cost (regular time)	67,400	Baht/month
14.) Labor cost (overtime)	56.25	Baht/man/hour
15.) Average holding time waiting for customer request	22.60	days

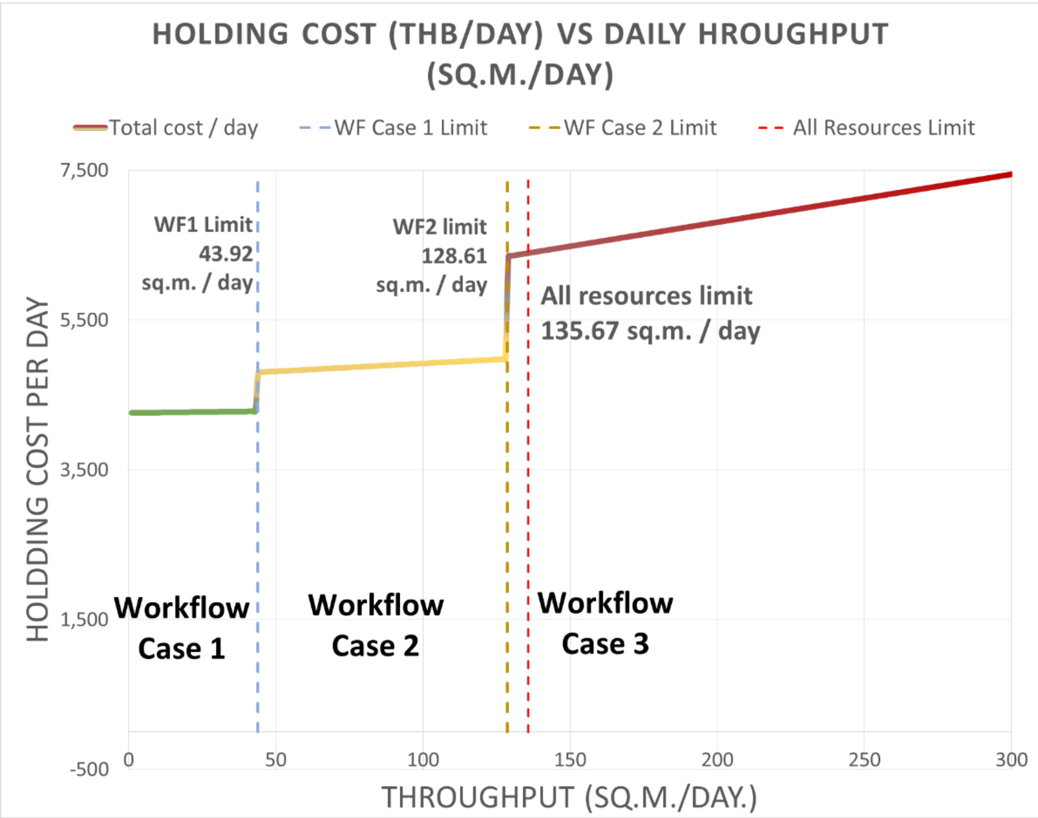

Figure 10 Estimated Financial Cost Accordance with Throughput

Production throughput and average wall panel area are estimated in period between 01/10/2015 and 31/07/2016. Furthermore, weight average cost of capital is averaged from 3 public companies limited in the same industry, and average monthly wall panel revenue is 5,054,790 THB.

According to Figure 10, it shows correlation between holding cost and throughput of the system as shown as its equations below;

$$x \le 43.92; \quad y = 0.5235x + 4261.7 \quad (1)$$

$$43.92 < x \le 128.61; \quad y = 2.1104x + 4711.7 \quad (2)$$

$$x > 128.61; \quad y = 6.4000x + 5524.6 \quad (3)$$

Where x is daily throughput (sq.m./day), and y is total holding cost per day (Baht/day).

Basically, daily throughput range between 0 and 43.92 sq.m./day, system would be operated in workflow case 1 which is the lowest lead time, and total holding cost as shown in equation (1). When daily throughput is driven further boundary of 43.92 sq.m./day, system would be turned to workflow case 2, and total holding cost would shift significantly to total holding cost's equation (2). It shifts total holding cost up 12.13% immediately at daily throughput of 44.00 sq.m./day due to fully utilization of moveable A-Frame rack, which causes increases in lead time, and number process on outdoor stockyard area. Increase in total holding cost consists of increases in outdoor leasing cost, and overtime labor cost on outdoor stockyard area. Furthermore, when daily throughput is driven further boundary of 128.61 sq.m./day, system would be turned to workflow case 3, and total holding cost would shift significantly to total holding cost's equation (3). It shifts total holding cost up 27.41% immediately at daily throughput of 129 sq.m./day due to fully utilization of moveable A-Frame rack, and spare slot on outdoor stockyard area, which causes additional increases in lead time, and number process on indoor stockyard area. Increase in total holding cost in this case consists of increases in indoor leasing cost, and overtime labor cost on indoor stockyard area. Lastly, beyond throughput of 135.67 sq.m./day, all of inventory areas are theoretically fully utilized and handle process cannot be operated after that point.

3. Literature Review

3.1. Introduction to Precast Concrete

Precast concrete element is concrete that has been processed and prepared, such as casted and cured, in some locations and travelled to final location or site's location. Precast concrete would benefit the project in term of total cost which depends on each country. For instance, in some countries, precast concrete would avoid expensive haulage or VAT, or precast concrete elements are shipped from another country where manufacturing and haulage cost are low. (Elliott, K. S., 2002)

3.2. Precast Concrete System in Thailand

In these days, in developing countries, precast concrete system is highly adopted with slightly growth rate which recorded as a key driven of industrialization and economic growth, especially in emerging countries in Asia such as China, Thailand, and Vietnam (Elematic, 2010). Hence, there are various studies that related to precast concrete in different perspectives, several problematic issues are stated, then proper approaches, tools, and methods are adopted to provide appropriate solution for each study. In perspective of another study (Waroonkun, T. and Koojaroenpaisan, R., 2011), the issue of factors that impact on the adopting of precast concrete system has been stated. After they received 160 intense survey from target group in Chiang Mai, and Bangkok in Thailand which are designer (63%), construction manager (21%), project administrator (9%), builder/contractor (5%), and project owner (2%) and performed ANOVA and analyzed on final four-factor solution, result showed that product characteristics, which include skilled labor, safety, waste material, and construction schedule, recorded as the highest significant factor that impact on the adoption of precast concrete system. On the other words, the authors registered factor of product characteristic with 4 sub-factors as the major factors of the problems. Moreover, to solve those and gain high probability of successful adopting precast concrete system, they recommended to minimize skilled labor, take advantage of using machinery as major tools, design precast system that reduce construction time of building structure at least 60% and reduce waste in the system. Hence, it is clearly that waste is one of potential problematic issues in this industry. Reducing and eliminating waste in precast factory issues has been investigated by both local and oversea researchers, while principle of manufacturing system becomes more important in construction which use in precast concrete factory to solve those problem.

3.3. Investigate in Waste Issue in Precast Concrete Factory and Their Approaches

For waste reduction and elimination study (Deffense, J. and Cachadinha, N., 2011), they investigated problem of waste occurring in 9 precast concrete factory in Portugal, then one of them is selected to implement Lean solution and complete deep analysis of its benefit as a case study. The objectives are purposed to reduce waste production, reduce lead-time, increase productivity, and increase job satisfaction with low cost techniques. To find a solution, Lean philosophy is adopted, and each factory is divided into 5 specific researching areas which are steel inventory, aggregates' inventory, molding process, vibration process, stocks of finished products and work area. Factory visit, interviews, desk research, and other lean tools, which are Value Stream Mapping (VSM), Kanban, 5S (Sorting, Stabilize, Systematic Cleaning, Standardizing, and Sustaining), Pull production principle, Just-in-Time, and Cellular Manufacturing, are used as research method, then Change Proposals is written, and in-depth analysis and conclusion are performed. As a result, steel inventory reduced area by 42% with financial reduce by 50%, work efficiency increased with lower space required, overall production increase by 58% with higher job satisfaction. However, stock area was not implemented because of disallowed by the company. The company revealed that order is not constant, depending on season. Authors mentioned that large stock is needed when orders are purchased to balance the difference in orders. Moreover, Dawood, N. and Marasini, R., (2003) stated that seasonality is unavoidable situation which create a stock that result of imbalance in system.

Furthermore, it has similar study in Thailand (Tanompandseree, N., 2006), he stated problematic issue that even market demand is rising in Thailand, lacking of good management and understand in precast concrete system lead to less develop in construction industry. Objectives are purposed to study and analyze in overall area of production, logistic, and erection precast concrete elements. Both real casting on outside yard and in factory system with two construction projects that similarly produce precast concrete wall panel are studied to compare pros and cons of each system. Then Lean philosophy is mentioned in his study to reduce waste in the system and construct guideline to improve the process. Moreover, as a result, wastes in system are identified with their root causes and suggestions. In part of inventory in both system, stock area, sequence, and location should be aligned with sequence of erection to avoid waste in motion and waiting which is double-handing and waiting of crane at construction site. However, as civil engineering thesis, the author provides explanation in technical area deeper than others.

Moreover, a study in Taiwan (Ko, C. H., 2010) stated to reduce waste in precast factory in scope of waste occurring in finished goods inventory. The objective is to develop a framework to reduce finished good inventory for precast concrete factory with maintained capacity among demand variability. This is the first study that appraise production time buffer by considering demand variability and using multi-objective genetic algorithms to arrange production schedule. In comparison to Deffense, J. and Cachadinha, N., (2011), and Tanompandseree, N., (2006), they studied in similar field, but Ko, C.H. (2010) focused deeply in area of reducing waste in finished goods inventory, while others considered in overall picture in several relative processes. It is surely that different approaches are adopted, but they aim similar to reduce waste in system.

In detail of Ko, C.H. (2010)'s study, The framework is separated into 3 parts which are time buffer to maintain capacity, due date adjustment that adjust production dates close to erection dates to reduce inventory and still satisfy demand, and integrate multi-objective genetic algorithms to manage production sequence and schedule. To optimize at minimal cost and production duration, the author adopted Multi-Objective Genetic Local Search Algorithm or MOGLS (Ishibuchi, H. and Murata, T., 1998) as a prototype of optimizing equation. In this study, the author reflected clearly nature of precast concrete factory and construction industry which is, for example, demand is not constant, construction projects are complicate, full of uncertainties, and vary with environment that tend precast concrete manufacturers to deal with various challenges, include plenty of inventory, to satisfy their customers. Moreover, a construction project, which is a precast concrete structure of 4 stories with 1 basement shopping mall which consists of 1671 beam, and 317 column components, is set as a case study to describe clearly results. After implemented in the project, the result showed that average finished goods inventory is deducted by 16%, while those 3 frameworks result good performance in both satisfying demand and fulfilling production capacity, and reduce potential risk, such as precast concrete fabricators' risk of succumbing, capacity loss or increased inventory costs to demand variability. Moreover, the author assumes that unit cost of inventory equals to 1, while unit cost of delay equals to 10, which might be useful as prototype for other cases that real cost is unknown. However, impact of overtime is not consider in production scheduling.

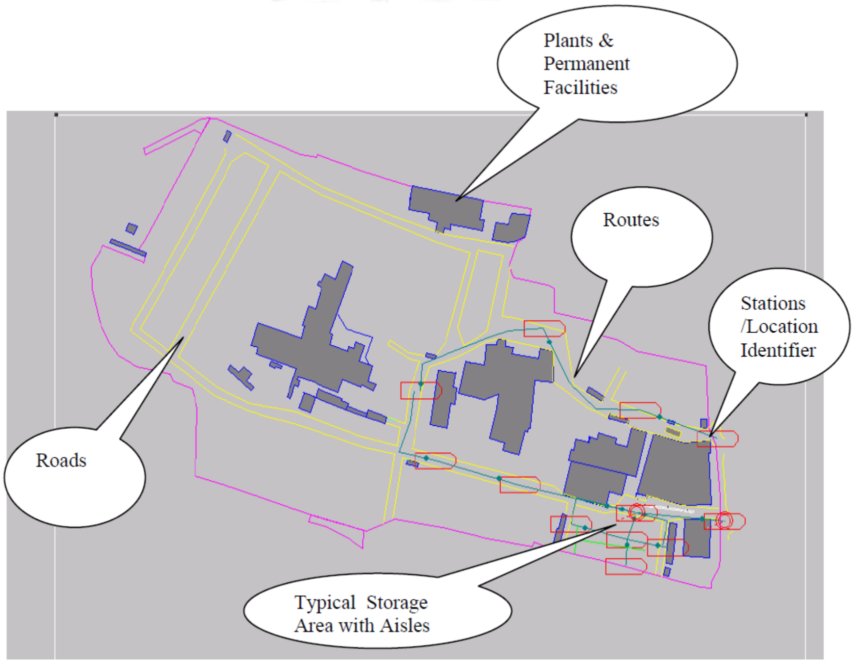

Figure 11 Sample layout and modelling of stockyard operations in ARENA (Dawood, N. and Marasini, R., 2000)

In addition, Dawood, N. and Marasini, R., (2000) has been studied in similar area in UK which focused on scope of solving on stockyard problem serving dynamic seasonal demand. Basically, demand is peak in summer, but low in winter. To satisfy those demand, large stock is built in winter, and dispatched in summer (Dawood, N. N., 1995). The authors aim to initiate proper methodology to manage stockyard layout planning by using ARENA 4.0 to build simulation model with what-if scenario which scope their study from after goods produced, picking to stock area, and pick to loading on truck. Various layouts, product arrangement to stock locations, and order picking policies are used in their model, and their performance index are vehicle waiting time, vehicle queue lengths stockyard space utilization, and the cost of storage and dispatch of products. To simplify, this study aims to minimize cost with maximize efficiency level. Moreover, a precast factory in UK has been set as case study, but the factory produced in different type of precast concrete products which consist of paving, walling, roofing, and garden product as non-structural components. Hence, work procedure and processes might be a bit different, compare to precast concrete wall panel. However, refer to simulation output, even though final outcome could not be presented at this stage of development, they promised that simulation outcomes from picking 5 products with zoning area concept of order picking, as shown in Figure 11, are appropriate methodology for developing the simulation model.

After that, in 2001, Marasini, R., Dawood, N. N. et al., (2001) has developed previous their study Dawood, N. and Marasini, R., (2000) which focused similarly on stockyard layout planning and trying to construct its model to find out significant factors that affects its efficiency among seasonal demand that create dynamic in stockyard. They adopted not only ARENA to build simulation model, but also integrated multi-software, as shown in Figure 12, Lean philosophy, statistic knowledge, and optimization equations (min. total cost of handling), with case study in precast concrete factory in UK. Genetic algorithm (GA) has been used to serve optimization purposes by fixed storage spaces, and allocate product in these spaces. In addition, they studied in same precast factory as same as before. One different point of their study is that the authors purposed to suggest proper framework as their result, instead of providing several numerical result data as other authors. However, even though final outcome still could not be presented at this stage of development, they promised that simulation outcomes from same sampling as previous work, as shown in Figure 13, are appropriate methodology for developing the simulation model.

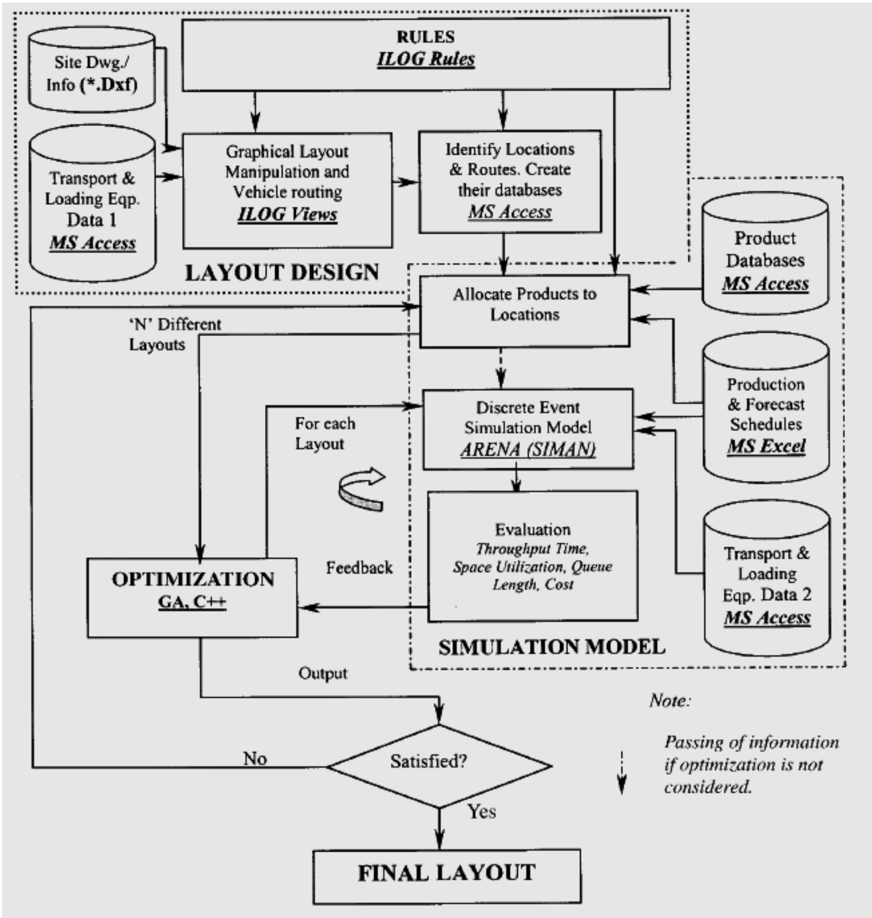

Figure 12 Integration of simulation model with other components

(Dawood, N. and Marasini, R., 2000)

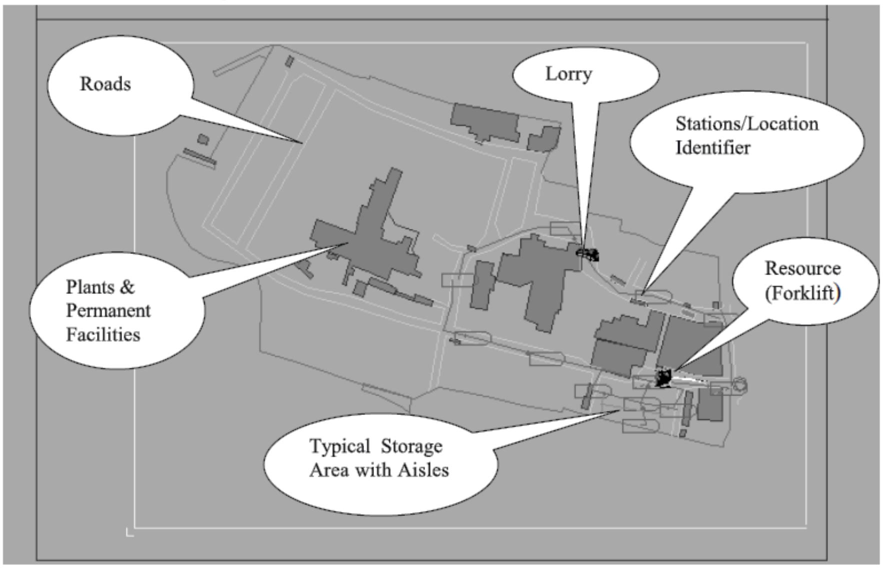

Figure 13 Sample layout and modelling of stockyard operation in ARENA

(Dawood, N. and Marasini, R., 2000)

In conclusion, they suggested that the program and simulation have to be adapted and implemented in each factory to investigate appropriate significant factors and solution to improve its efficiency level For example from case study, number of products, number of workers, and number of area visited are highly correlated with loading time and queue time in stockyard, while number of packs on loading has no significant impact on loading time and queue time. Hence, improvement strategies would focus on adjusting those significant factors in factory to find optimum level by using that optimization and simulation model.

Then, in 2002, the authors (Marasini, R. and Dawood, N., 2002) introduced full developed simulation model with same purposes that could fully represents stockyard's performance in their case study. All processes that related to stockyard are considered which are ordering process, lorry arrival, matching order with lorry, routing and loading process as product arrival, and lorry out, consequently. Then "SimStock" was introduced as an integrated process simulation for planning and optimizing stockyard layouts which integrated Auto CAD, VBA Macro, MS Access, MS Excel, and Visual Basic program as additional tools from previous version. With this model, it could customize and integrate sales pattern (demand pattern), truck arrival pattern, loading policies, travel distance, storage location, stockyard layout mode of storage, and cost information to generate optimize stockyard layout that maximize efficiency and minimize total cost. As a result, after implemented in the same case study factory and presented to other 3 companies, it could be concluded that this simulation model, SimStock, is a potential tool to improve effectiveness of product allocation and stockyard management that could reduce 5 to 10% of delivery cost of product to customer, and could be used potentially as decision making tool. Moreover, with this full developed simulation model, 2D and 3D has been developed to support stockyard manager in order to design, visualize and monitor processes, and manage at real time of implementation. (Dawood, N. and Marasini, R., 2003)

4. Objective of Thesis

To design handling process in post-production stage for precast concrete manufacturer to efficiently satisfy production's throughput under fluctuating market demand.

5. Scope of Study

This study is based on real problematic situation in case study of precast concrete factory. The scopes of study contain 7 issues:

1.) Focus on wall panels product which is the majority product of this factory.
2.) Focus on handling processes in post-production which starts from finished production at tilting table in production line to loading onto truck.
3.) Focus to provide solution to support several of market demand situations based on assumptions.
4.) Output of improvement would come from simulation model.
5.) Production process is assumed that wall panels are produced in accordance with sequence of installation which reflect existing situation in case study.
6.) Stockyard layout is well-organized and shared for every projects.
7.) Inventory level in calculation is focused on work-in-process inventory that affected by internal factors, such as production throughput. Excess inventory due to waiting for customer requested is neglected due to it is uncontrollable external factors, and would be calculated as average value, if it is necessary.

6. Proposed Methodology

This study plan to use various methods and tools to identify problem and investigate proper result:

1.) **Framework of 7 Wastes of Lean Manufacturing Principle**

7 Wastes of Lean Manufacturing principle is applied as a framework to investigate and categorize reducible wastes in the system. Moreover, applying 7 Wastes would simplify problematic issues in order to identify its root cause, consequently. However, waste of overproduction and defect are excluded because they are related into this study.

2.) **Little's Law (I = R x T)**

Little's Law is applied to measure work-in-process (WIP) inventory level by inputting lead time from VSM, and throughput from gathered data. From Little's Law, inventory level is easily clarified, and estimated in perspective of financial number, such as opportunity cost, and leads to estimate workforce cost, and land leasing cost. In addition, all reducible identified wasted and WIP would be turn into aspect of cost which mainly affect directly to the firm.

3.) **ARENA Simulation Model**

Developing simulation model is a key method that uses to investigate solution of this study by using ARENA program. Production schedule, delivery schedule, existing processes, and resources are integrated to this simulation model to reflect system's performance in high season period. After that, resources in model are adjusted to result positive different performance to serve demand in high season as its output.

4.) **Trade-Off Analysis**

Lastly, results of simulation model are turned to financial aspect which is opportunity to reduce cost and increase revenue versus additional investment with payback period of solutions that called Trade-off Analysis. This analysis would be a final result of this study that might affect directly to authorize decision maker who could approve those investments.

7. Improvement Approaches and Schedule

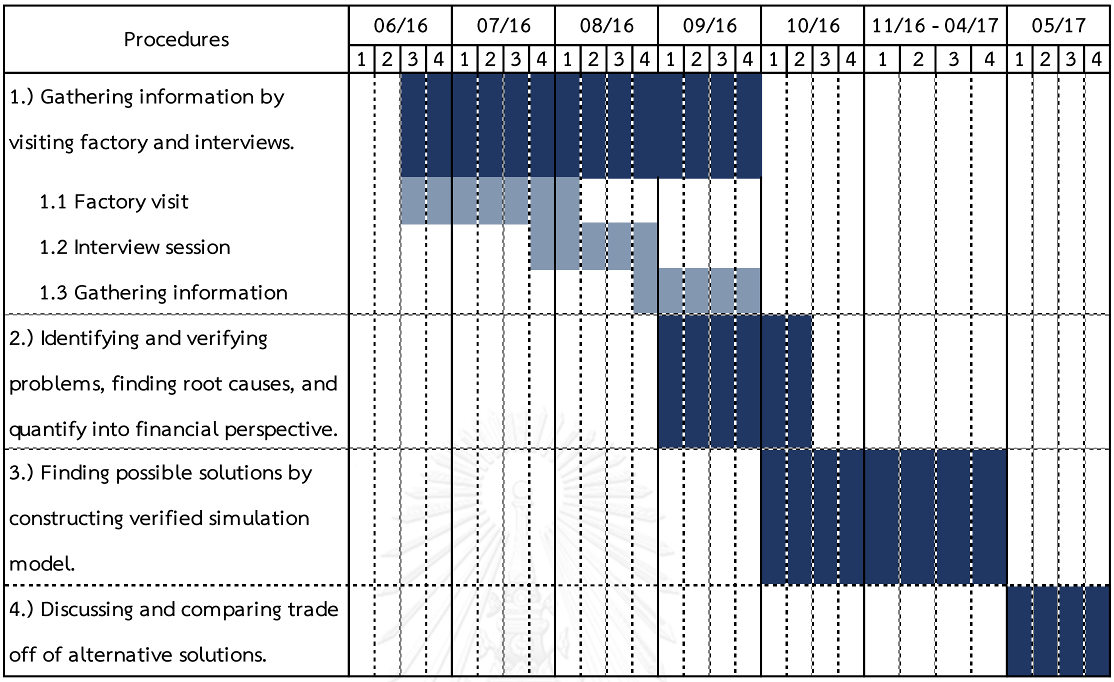

Figure 14 Thesis's Schedule

To improve performance of handling process in post-production stage in the case study, approaches are divided into 5 phrases as shown in Figure 14.

1.) **Gathering information by visiting factory and interviews.**

In study scope of post-production stage, to understand current situation, and recognize factory's problems, it required to understand big picture, existing workflow and processes of the factory. Hence, establish interview sessions with relevant parties, which are factory owner, factory manager, and other managers, will provide inside information and current problematic issues. Moreover, weekly factory visit will benefit in order to perceive a clear understanding in workflow, and problematic issues. Some available historical data are used to reflect current performance of the factory.

2.) **Identifying and verifying problems, finding root causes, and quantify into financial perspective.**

From interview session, factory visit, and historical data, framework of value streaming mapping (VSM) is partial applied to illustrate workflow of post-production stage because VSM can present a clear cut of a problematic point in the workflow.

Nonetheless, problematic issues from VSM have to be approved or rechecked with information from factory visit, and interviews.

After that, collected information, and historical data are analyzed based on framework of 7 wastes of lean manufacturing principle to figure out its problems, root-causes, and reducible wastes in handling process in post-production stage. Then they are quantified in aspect of financial impact to company in monthly expenditure. It benefits to simplify measurement of current performance, and improvement in the future. Furthermore, quantified results in financial aspect will help management, or authorized decision maker to select improvement solutions.

3.) Finding possible solutions by constructing verified simulation model.

It is unrealistic to do several experiments in routine operating factory and measure its improvement. Hence, verified simulation model by using ARENA program is chosen in this study to perform those experiments and measure its improvements. To complete verified simulation model, it requires to collect necessary data such as demand, processing time, waiting time, etc.

After verified simulation model is completed, the model is used to perform alternative scenarios to result improvement outcomes, as shown in Table 7. Alternative scenarios of the model are classified into 2 parts which are part of historical demand of data collected period with alternated resource (scenario 1-8), and part of alternated forecasting demand with the best practice to represent forecasted improvement outcomes in each expected situations (scenario 9-17). According to the first part, for simulation model with historical demand, purposes are to reflect current performance, and find the best practice. Scenario 1 is constructed to reflect current system that is used as benchmark to compare with scenario 2 to 8. For scenario 2, sequence of stocking packaged rack in outdoor stockyard is improved in comparison to scenario 1 which starts stock packaged rack at the nearest row from transfer car. It has no initial investment cost as well. Furthermore, number of moveable rack of each type is add up in range of 5 from total number of 20 to find the best range number of rack. However, the study shows and defines range of best practice’s number as scenarios that showed in Table 7. Then, sub-scenarios are performed and shown in range number of rack at ± 1 to reach the best number.

Table 7 Alternative Scenarios in Simulation Model

Scenario	Sub-Scenario	Demand Pattern	Rack Status	Number of Moveable A-Frame Rack	Number of Moveable Vertival Slot Rack	Sequence of Stocking Rack in Outdoor Stockyard	Compare To Scenario
Part 1: input based on current demand							
1 (C)		Historical	Current	17	-	Current	-
2 (S)		Historical	Current	17	-	Improved	1
3 (A35)		Historical	Increased	35	-	Improved	1
	3.5 (A39)	Historical	Increased	39	-	Improved	1
4 (A40)		Historical	Increased	40	-	Improved	1
	4.5 (A41)	Historical	Increased	41	-	Improved	1
5 (A45)		Historical	Increased	45	-	Improved	1
6 (V35)		Historical	Increased	-	35	Improved	1
	6.5 (V36)	Historical	Increased	-	36	Improved	1
7 (V37)		Historical	Increased	-	37	Improved	1
	7.5 (V38)	Historical	Increased	-	38	Improved	1
8 (V40)		Historical	Increased	-	40	Improved	1
Part 2: input based on forecast demand							
13 (HA17)		High:Low 65:35	Current	17	-	Improved	-
14 (MA17)		High:Low 50:50	Current	17	-	Improved	-
15 (LA17)		High:Low 35:65	Current	17	-	Improved	-
16 (HA40)		High:Low 65:35	Increased	40	-	Improved	13
17 (MA40)		High:Low 50:50	Increased	40	-	Improved	14
18 (LA40)		High:Low 35:65	Increased	40	-	Improved	15
19 (HH40)		High:Low 65:35	Increased	17	23	Improved	13
20 (MH40)		High:Low 50:50	Increased	17	23	Improved	14
21 (LH40)		High:Low 35:65	Increased	17	23	Improved	15

For the second part, with that best number of rack, demand patterns are varied on several ratio of verified high season to low season demand in 3 patterns, as shown.

1.) 65 % of high season demand pattern to 35 % of low season demand pattern with using existing rack type and using another rack type.

2.) 50 % of high season demand pattern to 50 % of low season demand pattern with using existing rack type and using another rack type.

3.) 35 % of high season demand pattern to 65 % of low season demand pattern with using existing rack type and using another rack type.

Moreover, in this study, even though moveable vertical slot rack benefits significantly to reduce total cost at site work which is out of thesis's scope, this type of rack is integrated and combined in simulation model in scenario 6-8 and 15-17.

4.) Discussing and comparing trade off of alternative solutions.

From results of alternative scenarios, there are 2 main measurements which are measurements of operating outcomes, and financial outcomes. Measurements of operating outcomes consist of unit total holding cost (Baht/sq.m.) and average daily throughput (sq.m./day). For financial outcomes, decreases in unit holding cost comes from decrease in proportion of operating on workflow case 2, and 3 which benefits directly to save monthly total holding cost. Total holding cost in each scenario is calculated from total holding cost equation in Figure 10, Exhibit 1, Exhibit 5, and Exhibit 9 depending on type, and combination of racks. Moreover, Increase in average daily throughput benefits to generate additional monthly profit at 150 Baht per additional sq.m. Then they are summed as total return per month. However, some improvements are required additional initial investment. Consequently, to make suggestions on any investments for the manufacturer, payback period of additional initial investment is calculated.

8. Explanation of Simulation Model

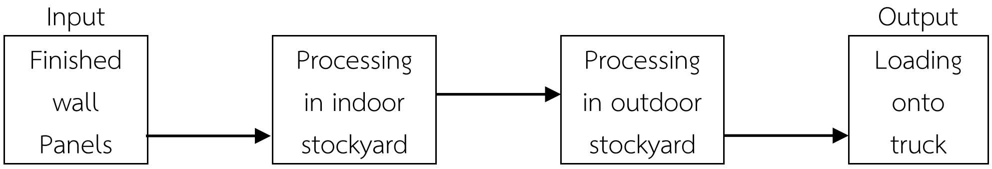

Figure 15 Overall Scope of Simulation Model

Purpose of constructing simulation model is to illustrate overall system of this study, and examine alternative solutions for improvements According to Figure 15, it shows overall scope of simulation model. Firstly, finished wall panels are delivered from production line as an input of this model. Number of wall panel per day is estimated based on seasonal market demand pattern as proportion of total products input that includes wall panel and slab. Then those finished wall panels will be processed in indoor stockyard and outdoor stockyard, respectively, and handle onto truck to be delivered to site-work on delivery day. However, in operation, wall panel and slab are produced from a same production line. Hence, some resources that used in wall panel handling in post-production stage are shared with slab, i.e. 10t crane, operator group 1, 20t crane, and operator group 2. Furthermore, in this simulation model, it is constructed in both workflow of wall panel, and slab to reflect resources pooling between wall panel, and slab.

8.1 Input of Simulation Model

For input in simulation model, refer to Table 8, inputs are quantified into pattern of high season demand, and low season demand of overall products. Then all products are classified to wall panels and slab as proportion of wall panel to all products. Then area, and difficulty are assigned individually for each wall panel. Basically, amount of wall panel are related to slab as normal distribution of mean and standard deviation at 82.80% and 0.169, respectively.

Table 8 Input Description in Simulation Model

No.	Detail	Type	Unit	p-value	Distribution
1	Product in high season period	Input	pcs.	0.451	Discrete Probability
2	Product in low season period	Inout	pcs.	0.801	Discrete Probability
3	Proportion of wall panel to all products	Inout	%	0.172	NORM(0.828, 0.169)
4	Area of wall panel	Inout	sq.m.	0.753	NORM(6.19, 1.42)
5	Difficulty of wall panel (50% of total wall panels)	Inout	-	0.99	DISC(0.5, 0, 1.0, 1)

Furthermore, each wall panel has been assign its area and difficulty as shown in Table 8. All of inputs are verified by statistical t-test between historical data and simulated data with 95% confidence level.

8.2 Simulation Flow of Workflow Case 1

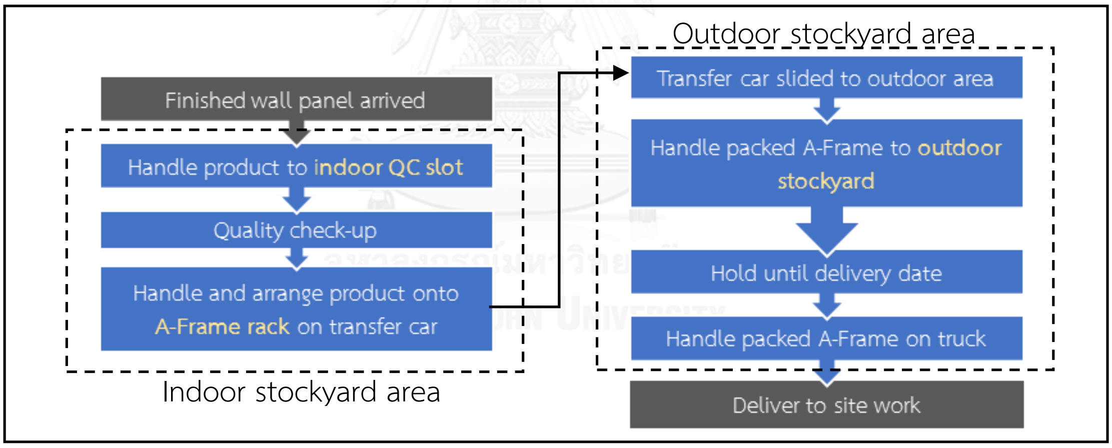

Figure 16 Brief Workflow Case 1

Table 9 Resources on Indoor Stockyard of Workflow Case 1

No.	Detail	Number
1	QC Team	3
2	Operators Gr.1	1
3	Crane 10 tons	1
4	Slot for QC Check-up	24
5	Moveable A-Frame	17

Table 10 Process and Waiting Activities in Indoor Stockyard of Workflow Case 1

No.	Detail	Type	Distribution
1	Handle product to QC slot	Process	2.5 + LOGN(2.93, 1.25)
2	Quality check-up (difficult wall panel)	Process	NORM(14.8, 4.65)
3	Handle and arrange product onto A-Frame rack on transfer car	Process	0.5 + GAMM(1.14, 4.2)
4	Holding for customer in high season	Waiting	-0.5 + GAMM(11.4, 1.59)
5	Holding for customer in low season	Waiting	-0.5 + GAMM(5.16, 1.51)

To explanation of workflow case 1, simulation model is separated into 2 parts which are processes on indoor stock area and outdoor stockyard area. Firstly, for indoor stockyard area in workflow case 1, refer to Figure 16 and Table 9, finished wall panels are handled from tilting table to slots for quality checking. It requires operators group 1, which consists of 4 workers, and 10 tons overhead crane. For quality checking, 50% of all wall panel requires quality checking because those wall panels have large opening which assigned as high difficulty (difficulty = 1). After quality checked, wall panels are handled into moveable A-Frame rack on transfer car by operators group 1, and 10 tons overhead crane. To arrange wall panels in moveable A-Frame rack, there are 2 conditions which are summation of wall panels' area not greater than 60 sq.m., and summation of difficulty level not greater than 4. Process time and waiting time of every processes are verified and shown in Table 10 that used as inputs in simulation model.

Secondly, for outdoor stockyard area in workflow case 1, refer to Figure 16 and Table 11, when packaged wall panel rack moved out to outdoor stockyard by transfer car, each rack is handled to stock in stockyard row from row no. 1 to 14, respectively. Then it has to wait for customer requesting, or until delivery date on construction plan. Packaged wall panels are handled onto truck for delivery. Process time of every processes are verified and shown in Table 12 that used as inputs in simulation model.

Table 11 Resources on Outdoor Stockyard of Workflow Case 1

No.	Detail	Number
1	Operators Gr.2	1
2	Crane 20 tons	1
3	Transfer car	1
4	Stock capacity on row 1	4
5	Stock capacity on row 2	4
6	Stock capacity on row 3	4
7	Stock capacity on row 4	4
8	Stock capacity on row 5	4
9	Stock capacity on row 6	4
10	Stock capacity on row 7	4
11	Stock capacity on row 8	4
12	Stock capacity on row 9	4
13	Stock capacity on row 10	4
14	Stock capacity on row 11	4
15	Stock capacity on row 12	4
16	Stock capacity on row 13	4
17	Stock capacity on row 14	4
18	Outdoor spare slot	350

Table 12 Relevant Process and Waiting Activities of Workflow Case 1

No.	Detail	Type	Unit	Distribution
1	Transfer car moved out	Process	min.	1
2	Handle packed rack to stock on row 1	Process	min.	5 + GAMM(1.32, 2.21)
3	Handle packed rack to stock on row 2	Process	min.	4.5 + GAMM(1.32, 2.21)
4	Handle packed rack to stock on row 3	Process	min.	4 + GAMM(1.32, 2.21)
5	Handle packed rack to stock on row 4	Process	min.	3.5 + GAMM(1.32, 2.21)
6	Handle packed rack to stock on row 5	Process	min.	3.5 + GAMM(1.32, 2.21)
7	Handle packed rack to stock on row 6	Process	min.	4 + GAMM(1.32, 2.21)
8	Handle packed rack to stock on row 7	Process	min.	4.5 + GAMM(1.32, 2.21)
9	Handle packed rack to stock on row 8	Process	min.	5 + GAMM(1.32, 2.21)
10	Handle packed rack to stock on row 9	Process	min.	5.5 + GAMM(1.32, 2.21)
11	Handle packed rack to stock on row 10	Process	min.	6 + GAMM(1.32, 2.21)
12	Handle packed rack to stock on row 11	Process	min.	6.5 + GAMM(1.32, 2.21)
13	Handle packed rack to stock on row 12	Process	min.	7 + GAMM(1.32, 2.21)
14	Handle packed rack to stock on row 13	Process	min.	7.5 + GAMM(1.32, 2.21)
15	Handle packed rack to stock on row 14	Process	min.	8 + GAMM(1.32, 2.21)
16	Handle packaged rack onto truck	Process	min.	3.5 + 12 * BETA(0.436, 0.555)
17	Round trip delivery tralvel time	Waiting	min.	480

8.3 Simulation Flow of Workflow Case 2

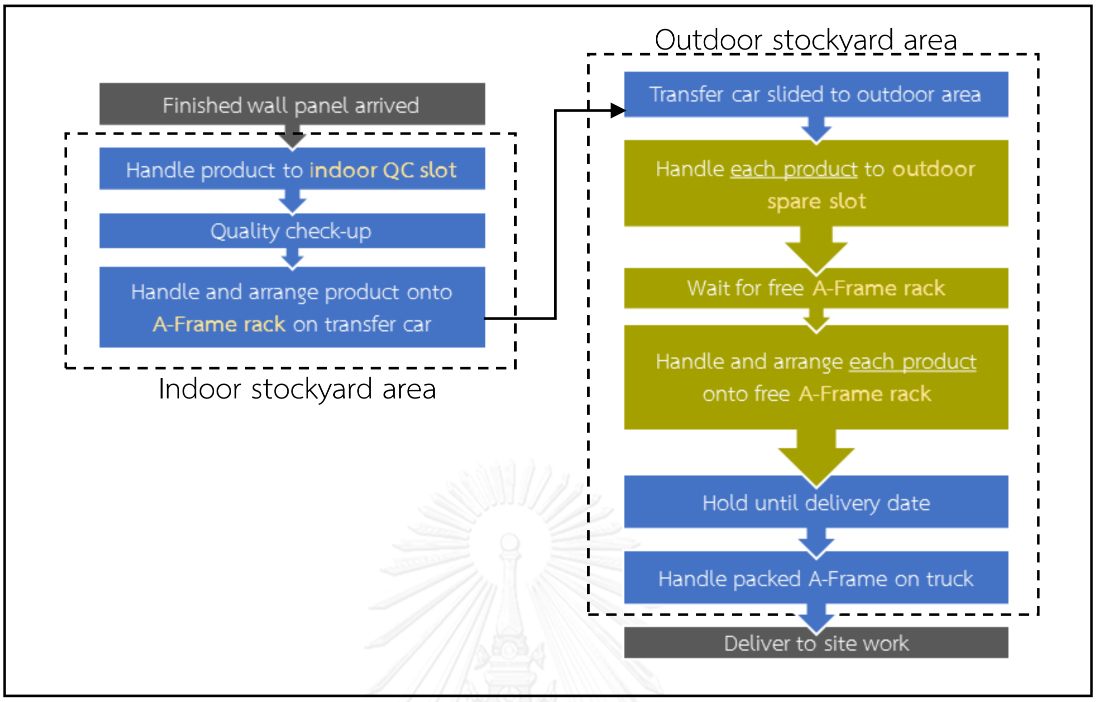

Figure 17 Brief Workflow Case 2

Table 13 Resources on Indoor Stockyard of Workflow Case 2

No.	Detail	Number
1	QC Team	3
2	Operators Gr.1	1
3	Crane 10 tons	1
4	Slot for QC Check-up	24
5	Moveable A-Frame	17

Table 14 Process and Waiting Activities on Indoor Stockyard of Workflow Case 2

No.	Detail	Type	Distribution
1	Handle product to QC slot	Process	2.5 + LOGN(2.93, 1.25)
2	Quality check-up (difficult wall panel)	Process	NORM(14.8, 4.65)
3	Handle and arrange product onto A-Frame rack on transfer car	Process	0.5 + GAMM(1.14, 4.2)
4	Holding for customer in high season	Waiting	-0.5 + GAMM(11.4, 1.59)
5	Holding for customer in low season	Waiting	-0.5 + GAMM(5.16, 1.51)

To explanation of workflow case 2, simulation model is separated into 2 parts which are processes on indoor stock area and outdoor stockyard area. Firstly, for indoor stockyard area in workflow case 2, refer to Figure 17 and Table 13, finished wall panels are handled from tilting table to slots for quality checking. It requires operators group 1, which consists of 4 workers, and 10 tons overhead crane. For quality checking, 50% of all wall panel requires quality checking because those wall panels have large opening which assigned as high difficulty (difficulty = 1). After quality checked, wall panels are handled into moveable A-Frame rack on transfer car by operators group 1, and 10 tons overhead crane. To arrange wall panels in moveable A-Frame rack, there are 2 conditions which are summation of wall panels' area not greater than 60 sq.m., and summation of difficulty level not greater than 4. Process time and waiting time of every processes are verified and shown in Table 14 that used as inputs in simulation model.

Secondly, for outdoor stockyard area, refer to Figure 17, and Table 15, when moveable A-Frame rack are fully utilized due to increase in demand, workflow will turn from workflow case 1 to case 2. Additional handling processes in outdoor stockyard are required to balance overall throughput, and wait for available of moveable A-Frame. Those additional processes are handling each product from transfer car to outdoor spare slot, and handling and arranging each product from outdoor spare slot to available rack individually, instead of handling a whole rack of packaged wall panels. However, using A-Frame rack, handling and arranging each product from outdoor spare slot to available rack is required to satisfy conditions of summation of wall panels' area not greater than 60 sq.m., and summation of difficulty level not greater than 4. But, when it turns to use moveable vertical slot rack, only condition of arranging wall panel on the rack is summation of wall panels' area not greater than 60 sq.m. Process time and waiting time of every processes are verified and shown in Table 16 that used as inputs in simulation model.

Table 15 Resources on Outdoor Stockyard of Workflow Case 2

No.	Detail	Number
1	Operators Gr.2	1
2	Crane 20 tons	1
3	Transfer car	1
4	Stock capacity on row 1	4
5	Stock capacity on row 2	4
6	Stock capacity on row 3	4
7	Stock capacity on row 4	4
8	Stock capacity on row 5	4
9	Stock capacity on row 6	4
10	Stock capacity on row 7	4
11	Stock capacity on row 8	4
12	Stock capacity on row 9	4
13	Stock capacity on row 10	4
14	Stock capacity on row 11	4
15	Stock capacity on row 12	4
16	Stock capacity on row 13	4
17	Stock capacity on row 14	4
18	Outdoor spare slot	350

Table 16 Process and Waiting Activities on Outdoor Stockyard of Workflow Case 2

No.	Detail	Type	Unit	p-value	Distribution
1	Transfer car moved out	Process	min.		1
2	Handle packed rack to stock on row 1	Process	min.	0.465	5 + GAMM(1.32, 2.21)
3	Handle packed rack to stock on row 2	Process	min.	0.564	4.5 + GAMM(1.32, 2.21)
4	Handle packed rack to stock on row 3	Process	min.	0.642	4 + GAMM(1.32, 2.21)
5	Handle packed rack to stock on row 4	Process	min.	0.453	3.5 + GAMM(1.32, 2.21)
6	Handle packed rack to stock on row 5	Process	min.	0.357	3.5 + GAMM(1.32, 2.21)
7	Handle packed rack to stock on row 6	Process	min.	0.524	4 + GAMM(1.32, 2.21)
8	Handle packed rack to stock on row 7	Process	min.	0.562	4.5 + GAMM(1.32, 2.21)
9	Handle packed rack to stock on row 8	Process	min.	0.680	5 + GAMM(1.32, 2.21)
10	Handle packed rack to stock on row 9	Process	min.	0.639	5.5 + GAMM(1.32, 2.21)
11	Handle packed rack to stock on row 10	Process	min.	0.597	6 + GAMM(1.32, 2.21)
12	Handle packed rack to stock on row 11	Process	min.	0.491	6.5 + GAMM(1.32, 2.21)
13	Handle packed rack to stock on row 12	Process	min.	0.456	7 + GAMM(1.32, 2.21)
14	Handle packed rack to stock on row 13	Process	min.	0.422	7.5 + GAMM(1.32, 2.21)
15	Handle packed rack to stock on row 14	Process	min.	0.508	8 + GAMM(1.32, 2.21)
16	Handle packaged rack onto truck	Process	min.	0.359	3.5 + 12 * BETA(0.436, 0.555)
17	Round trip delivery tralvel time	Waiting	min.		480
18	Handle each product from transfer car to outdoor spare slot	Process	min.	0.787	3.5 + LOGN(3.09, 2.85)
19	Handle each product from outdoor spare slot to rack	Process	min.	0.504	0.5 + GAMM(1.14, 4.2)

8.3 Simulation Flow of Workflow Case 3

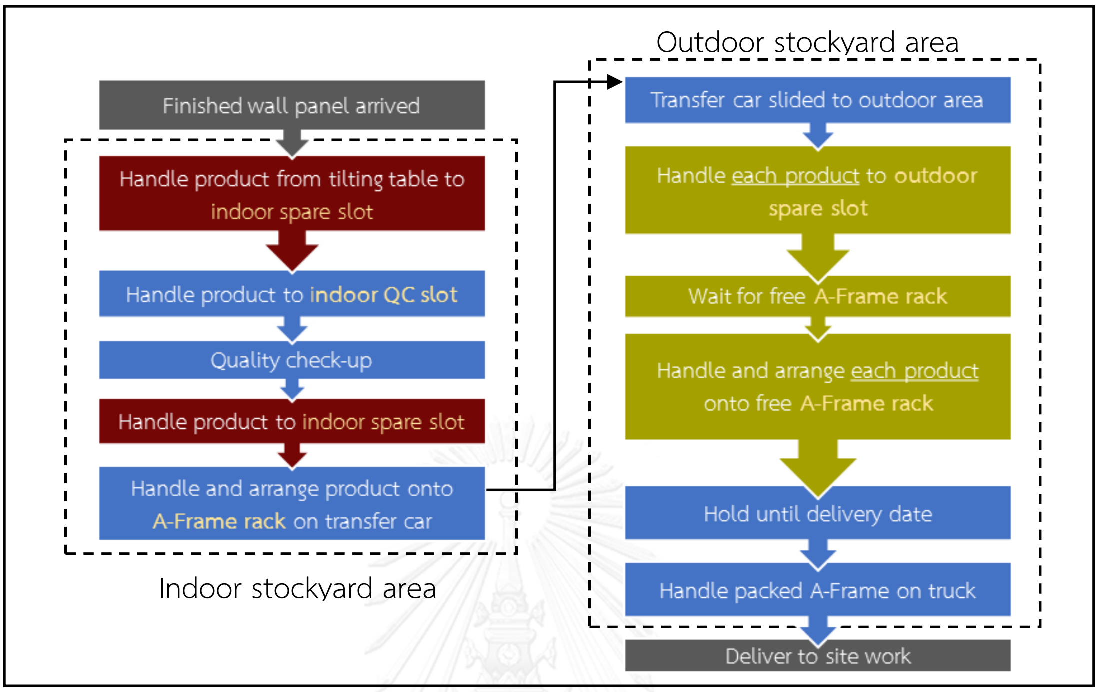

Figure 18 Brief Workflow Case 3

Table 17 Resources on Indoor Stockyard of Workflow Case 3

No.	Detail	Number
1	QC Team	3
2	Operators Gr.1	1
3	Crane 10 tons	1
4	Slot for QC Check-up	24
5	Moveable A-Frame	17
6	Indoor Spare Slot before QC	30
7	Indoor Spare Slot after QC	30

Table 18 Process and Waiting Activities on Indoor Stockyard of Workflow Case 3

No.	Detail	Type	Distribution
1	Handle product to QC slot	Process	2.5 + LOGN(2.93, 1.25)
2	Quality check-up (difficult wall panel)	Process	NORM(14.8, 4.65)
3	Handle and arrange product onto A-Frame rack on transfer car	Process	0.5 + GAMM(1.14, 4.2)
4	Holding for customer in high season	Waiting	-0.5 + GAMM(11.4, 1.59)
5	Holding for customer in low season	Waiting	-0.5 + GAMM(5.16, 1.51)
6	Handle product to indoor spare slot waiting for free slot before QC	Process	2.5 + LOGN(2.93, 1.25)
7	Handle product to indoor spare slot after QC waiting for free A-Frame	Process	2.5 + LOGN(2.93, 1.25)

To explanation of workflow case 3, simulation model is separated into 2 parts which are processes on indoor stock area and outdoor stockyard area. For indoor stockyard area, refer to Figure 18 and Table 17, when workflow of handling process turns to workflow case 3 due to fully utilized of outdoor spare slot, additional handling processes and resources in indoor stockyard are required to balance overall throughput, and wait for available of spare slot in outdoor stockyard. Process time and waiting time of every processes are verified and shown in Table 18 that used as inputs in simulation model.

Secondly, for outdoor stockyard area, refer to Figure 18, and Table 19, when moveable A-Frame racks are fully utilized due to increase in demand, workflow still operated in workflow case 1 to case 2. Additional handling processes in outdoor stockyard are required to balance overall throughput, and wait for available of moveable A-Frame. Those additional processes are handling each product from transfer car to outdoor spare slot, and handling and arranging each product from outdoor spare slot to available rack individually, instead of handling a whole rack of packaged wall panels. However, using A-Frame rack, handling and arranging each product from outdoor spare slot to available rack is required to satisfy conditions of summation of wall panels' area not greater than 60 sq.m., and summation of difficulty level not greater than 4. But, when it turns to use moveable vertical slot rack, only condition of arranging wall panel on the rack is summation of wall panels' area not greater than 60 sq.m. Process time and waiting time of every processes are verified and shown in Figure 20 that used as inputs in simulation model.

Table 19 Resources on Outdoor Stockyard of Workflow Case 2

No.	Detail	Number
1	Operators Gr.2	1
2	Crane 20 tons	1
3	Transfer car	1
4	Stock capacity on row 1	4
5	Stock capacity on row 2	4
6	Stock capacity on row 3	4
7	Stock capacity on row 4	4
8	Stock capacity on row 5	4
9	Stock capacity on row 6	4
10	Stock capacity on row 7	4
11	Stock capacity on row 8	4
12	Stock capacity on row 9	4
13	Stock capacity on row 10	4
14	Stock capacity on row 11	4
15	Stock capacity on row 12	4
16	Stock capacity on row 13	4
17	Stock capacity on row 14	4
18	Outdoor spare slot	350

Table 20 Process and Waiting Activities on Outdoor Stockyard of Workflow Case 2

No.	Detail	Type	Unit	p-value	Distribution
1	Transfer car moved out	Process	min.		1
2	Handle packed rack to stock on row 1	Process	min.	0.465	5 + GAMM(1.32, 2.21)
3	Handle packed rack to stock on row 2	Process	min.	0.564	4.5 + GAMM(1.32, 2.21)
4	Handle packed rack to stock on row 3	Process	min.	0.642	4 + GAMM(1.32, 2.21)
5	Handle packed rack to stock on row 4	Process	min.	0.453	3.5 + GAMM(1.32, 2.21)
6	Handle packed rack to stock on row 5	Process	min.	0.357	3.5 + GAMM(1.32, 2.21)
7	Handle packed rack to stock on row 6	Process	min.	0.524	4 + GAMM(1.32, 2.21)
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14	Handle packed rack to stock on row 13	Process	min.	0.422	7.5 + GAMM(1.32, 2.21)
15	Handle packed rack to stock on row 14	Process	min.	0.508	8 + GAMM(1.32, 2.21)
16	Handle packaged rack onto truck	Process	min.	0.359	3.5 + 12 * BETA(0.436, 0.555)
17	Round trip delivery tralvel time	Waiting	min.		480
18	Handle each product from transfer car to outdoor spare slot	Process	min.	0.787	3.5 + LOGN(3.09, 2.85)
19	Handle each product from outdoor spare slot to rack	Process	min.	0.504	0.5 + GAMM(1.14, 4.2)

Furthermore, arranging wall panels’ conditions can be changed due to changing type of moveable A-Frame rack to moveable vertical slot rack. By using moveable vertical slot rack, summation of wall panels’ area not greater than 60 sq.m. is only a condition for arranging wall panels.

In this study, each component of simulation model is verified accordance with historical data, including demand distribution in high and low season, area and difficulty of wall panel, process time of each process, and total overall output. Verifying model is performed by using statistical method (t-test) at 95% confidence level.

9. Results and Findings

In this study, results are divided into 2 parts, the first part contains scenario 1-8, and the second part contains scenario 9-17. For the first part, according to Table 22 , it shows results of scenario 1-8 which input is historical demand in data collecting period. Scenario 1 is the current stage of handling process in post-production stage. It constructed to use as a benchmark to compare operating and financial outcomes with other scenarios. In operating perspective, it has workflow case 1, 2, and 3 at 12.79%, 55.81%, and 31.40%, respectively. It is clearly that system mostly operates on workflow case 2 which has the highest proportion and has lead time as shown in Table 21. Hence, according to, Table 4, most of wastes are waste of handling each product to slot rack on outdoor stockyard, waiting for free A-Frame on outdoor stockyard, and double handling and arranging product onto free A-Frame rack on outdoor stockyard which are occur in workflow case 2. In operating outcomes, daily throughput and average unit holding cost are 105.70 sq.m./day, and 36.02 Baht/ sq.m., respectively.

In scenario 2, it is clearly that improving sequence of stocking rack in outdoor stockyard increases daily throughput by 2.10%, and decrease total holding cost per unit 5.65% because it significantly decreases workflow case 2 and 3 by 8.50 and 1.31 %, respectively, but the system still mostly operates on workflow case 2 and has wastes as same as scenario 1. However, it does not require any investments. Hence, without any switching cost, improving sequence of stocking rack in outdoor stockyard can be implemented immediately.

Table 21 Lead Time of Scenario 1 (Current System)

	WF Case 1	WF Case 2	WF Case 3
Category	**Lead Time / Rack (min)**	**Lead Time / Rack (min)**	**Lead Time / Rack (min)**
Indoor activity	164.04	164.04	207.29
Outdoor activity	134.48	1040.72	1040.72
Total	298.52	1204.76	1248.01

Table 22 Results of Scenario 1-5

Detail	Scenario 1	Scenario 2	Scenario 3	Scenario3.5	Scenario 4	Scenario 4.5	Scenario 5
Operating Aspects							
% of Workflow Case 1	12.79%	22.60%	58.96%	83.14%	100.00%	100.00%	100.00%
% of Workflow Case 2	55.81%	47.32%	25.00%	9.80%	0.00%	0.00%	0.00%
% of Workflow Case 3	31.40%	30.08%	16.04%	7.06%	0.00%	0.00%	0.00%
Sequence of Stocking Rack in Outdoor Stockyard	Current	Improved	Improved	Improved	Improved	Improved	Improved
Type of Rack	A-Frame	A-Frame	A-Frame	A-Frame	A-Frame	A-Frame	A-Frame
Num of A-Frame Rack	17	17	35	39	40	41	45
Num of Ver. Slot Rack	-	-	-	-	-	-	-
Number of Using Moveable Ver. Slot Rack	-	-	-	-	-	-	-
Total Working Day (days)	226	226	226	226	226	226	226
Total Working Month (months)	9	9	9	9	9	9	9
Total Output (sq.m.)	23,887.32	24,389.28	24,436.67	24,529.29	25,206.51	25,206.51	25,206.51
Total Holding Cost (Baht)	860,446.89	828,893.92	800,516.47	778,937.00	773,225.56	773,225.56	773,225.56
Benchmark scenario		1	1	1	1	1	1
Average Daily Throughput (sq.m./day)	**105.70**	**107.92**	**108.13**	**108.54**	**111.53**	**111.53**	**111.53**
% Increase		**2.10%**	**2.30%**	**2.69%**	**5.52%**	**5.52%**	**5.52%**
Total Unit Holding Cost (Baht/sq.m.)	**36.02**	**33.99**	**32.76**	**31.76**	**30.68**	**30.68**	**30.68**
% Decrease		**-5.65%**	**-9.06%**	**-11.84%**	**-14.84%**	**-14.84%**	**-14.84%**
Financial Aspects							
Estimated Profit of Wall Panel (Baht/sq.m.)		150	150	150	150	150	150
Estimated Saving from Using Vertical Slot Rack (Baht/rack)							
Initial Investment on Additional Rack (Baht)		-	1,260,000	1,540,000	1,610,000	1,680,000	1,960,000
Additional Rack (rack)		-	18	22	23	24	28
Estimated Cost per Rack (Bath)		70,000.00	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00
Average Direct Saving Per Month (Baht/month)		5,514.89	8,857.60	11,626.01	14,971.11	14,971.11	14,971.11
Average Saving on Site Per Month (Baht/month)							
Profit on Additional Throughput (Baht/month)		8,365.94	9,155.74	10,699.38	21,986.49	21,986.49	21,986.49
Total Return Per Month (Baht/month)		13,880.83	18,013.34	22,325.39	36,957.60	36,957.60	36,957.60
Payback Period (years)			5.83	5.75	3.67	3.83	4.50

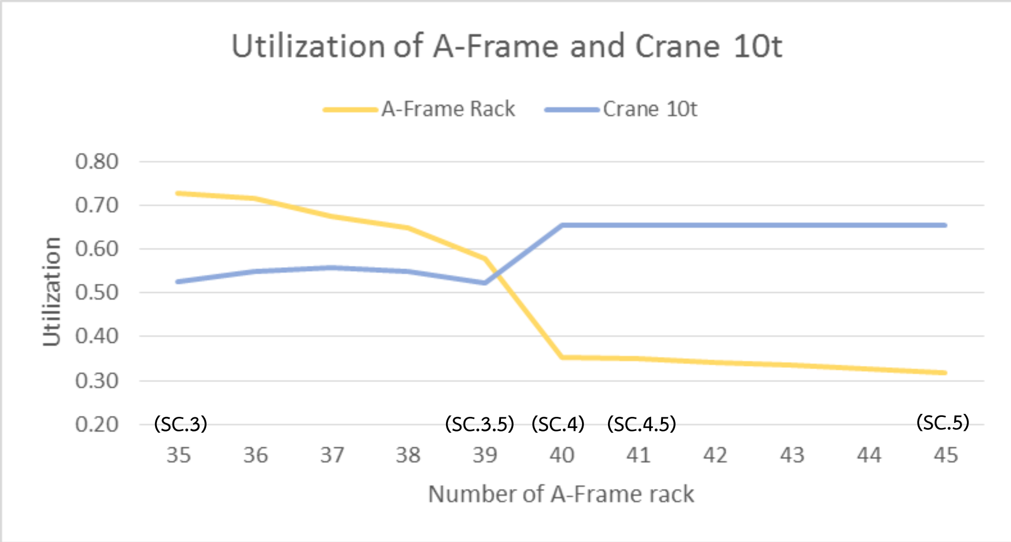


Figure 19 Utilization of A-Frame Rack and Crane 10t in scenario 3 – 5

Table 23 Lead Time of Scenario 5

	WF Case 1	**WF Case 2**	**WF Case 3**
Category	**Lead Time / Rack (min)**	**Lead Time / Rack (min)**	**Lead Time / Rack (min)**
Indoor activity	164.04	164.04	207.29
Outdoor activity	134.12	1040.72	1040.72
Total	298.16	1204.76	1248.01

Refer to Figure 19, when number and type of rack are varied by trial and error method, number of rack is trialed from 20 racks with additional of 5 racks to obtain best practice range. When best practice range obtained, it is adjusted to match the best practice number with range of ± 1 rack as its sub-scenarios. It shows that, after number of rack at 40, utilization of crane 10 tons is constant at 65.39% while utilization of A-Frame slightly decreases. Thus, bottle neck of the system is shifted from A-Frame rack to crane 10 tons after number of rack at 40 racks (scenario 4).

According to Table 22, it shows that 40 racks of moveable A-Frame rack with improved in sequence of stocking rack provides the highest improvement in operating outcomes. System totally operate in workflow case 1 which eliminate all wastes, except waste of deciding consequence of wall panel on rack because it still uses A-Frame rack, refer to Table 4. However, when compares lead time between current system (scenario 1) and 40 of A-Frame racks (scenario 4), they have the same lead time as shown in Table 21 and Table 23. Hence, improvement of performance and outcomes came from decreases in proportion of workflow case 2 and 3.

In comparison to current system in scenario 1, it decreases total unit holding cost to 30.68 Baht/sq.m. (-14.84%) and increase daily average throughput to 111.53 sq.m./day (+5.52%), and requires initial investment of 1.61 million Baht. With total 40 A-Frame racks, it saves direct holding cost 14,971.11 Baht/month and generates additional profit 21986.49 Baht/month, or monthly total return of 36,957.60 Baht/month. It also has payback period of 3.67 years.

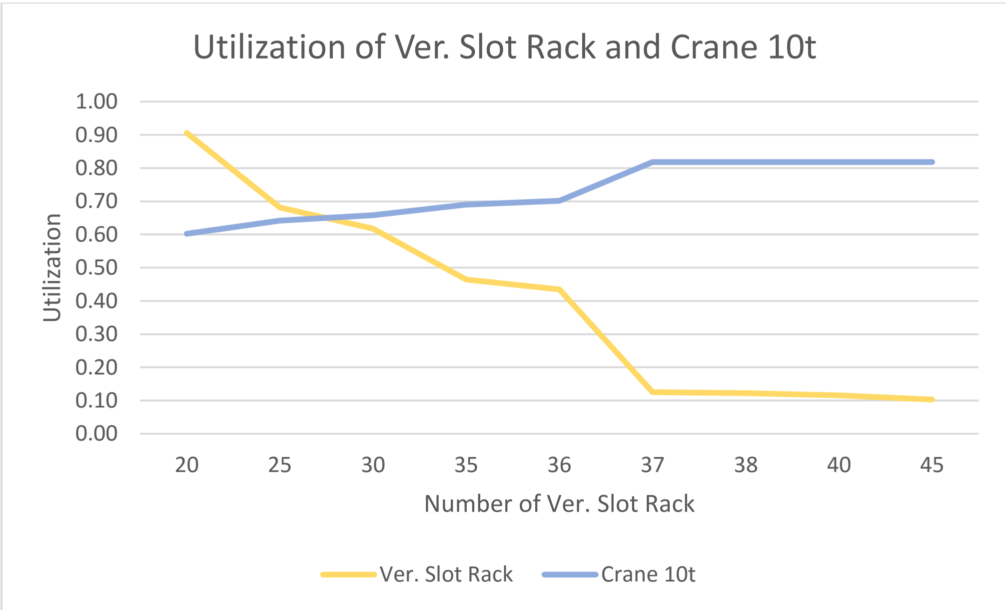


Figure 20 Utilization of Vertical Slot Rack and Crane 10t in scenario 6 – 8

Table 24 Lead Time of Scenario 7

Category	WF Case 1 Lead Time / Rack (min)	WF Case 2 Lead Time / Rack (min)	WF Case 3 Lead Time / Rack (min)
Indoor activity	142.53	142.53	186.21
Outdoor activity	121.91	1032.92	1032.92
Total	264.44	1175.45	1219.13

Refer to Figure 20, when number and type of rack are varied by trial and error method, number of rack is trialed from 20 racks with additional of 5 racks to obtain best practice range. When best practice range obtained, it is adjusted to match the best practice number with range of ± 1 rack as its sub-scenarios. It shows that, after number of rack at 37, utilization of crane 10 tons is constant at 81.79% while utilization of vertical slot rack slightly decreases. Thus, bottle neck of the system is shifted from vertical slot rack to crane 10 tons after number of rack at 37 racks (scenario 7).

According to Table 25, it shows that 37 racks of moveable vertical slot rack with improved in sequence of stocking rack provides the highest improvement in operating outcomes. System totally operates in workflow case 1 which eliminates all wastes, refer to Table 4. Waste of deciding consequence of wall panel on rack is eliminated in comparison to scenario 5 because of using vertical slot rack. It does not have limitation of sequence and total number of difficult wall panel on rack. However, when compares lead time between current system (scenario 1) and 40 of vertical slot racks (scenario 7), it decreases lead time as shown in Table 21, and Table 24. Hence, improvement of performance and outcomes came from decreases in proportion of workflow case 2 and 3, and decrease in lead time. Moreover, it is remarked that using vertical slot rack benefits to saving cost on-site which is out of this study's scope. However, it will be taken into account for this benefit as approximately saving on-site cost at 312.5 Baht per a usage of vertical slot rack. It is because wall panels on truck can be erected directly to a house. It eliminated process of unloading before erection that roughly saved 15 minutes per a usage of vertical slot rack.

In comparison using 37 vertical slot rack (scenario 7) to current system in scenario 1, it decreases total unit holding cost to 30.63 Baht/sq.m. (-12.84%) and increase daily average throughput to 114.92 sq.m./day (+8.73%), and requires initial investment of 4.44 million Baht. With total 37 vertical slot racks, it saves direct holding cost 15,656.93 Baht/month in factory and 17,152.78 Baht/month on-site, and generates additional profit 34,748.60 Baht/month, or monthly total return of 67,467.30 Baht/month. It also has payback period of 5.50 years.

Table 25 Results of Scenario 1, and 6 - 8

Detail	Scenario 1	Scenario 2	Scenario 6	Scenario 6.5	Scenario 7	Scenario 7.5	Scenario 8
Operating Aspects							
% of Workflow Case 1	12.79%	22.60%	85.78%	93.36%	100.00%	100.00%	100.00%
% of Workflow Case 2	55.81%	47.32%	9.48%	4.27%	0.00%	0.00%	0.00%
% of Workflow Case 3	31.40%	30.08%	4.74%	2.37%	0.00%	0.00%	0.00%
Sequence of Stocking Rack in Outdoor Stockyard	Current	Improved	Improved	Improved	Improved	Improved	Improved
Type of Rack	A-Frame	A-Frame	Ver. Slot	Ver. Slot	Ver. Slot	Ver. Slot	Ver. Slot
Num of A-Frame Rack	17	17					
Num of Ver. Slot Rack	-	-	35	36	37	38	40
Number of Using Moveable Ver. Slot Rack	-	-	478	454	494	494	494
Total Working Day (days)	226	226	226	226	226	226	226
Total Working Month (months)	9	9	9	9	9	9	9
Total Output (sq.m.)	23,887.32	24,389.28	25,206.51	25,314.70	25,972.24	25,972.24	25,972.24
Total Holding Cost (Baht)	860,446.89	828,893.92	803,934.86	801,530.04	795,454.42	795,454.42	795,454.42
Benchmark scenario		1	1	1	1	1	1
Average Daily Throughput (sq.m./day)	**105.70**	**107.92**	**111.61**	**112.01**	**114.92**	**114.92**	**114.92**
% Increase		2.10%	5.59%	5.98%	8.73%	8.73%	8.73%
Total Unit Holding Cost (Baht/sq.m.)	**36.02**	**33.99**	**31.87**	**31.66**	**30.63**	**30.63**	**30.63**
% Decrease		-5.65%	-11.52%	-12.10%	-14.97%	-14.97%	-14.97%
Financial Aspects							
Estimated Profit of Wall Panel (Baht/sq.m.)		150	150	150	150	150	150
Estimated Saving from Using Vertical Slot Rack (Baht/rack)			312.5	312.5	312.5	312.5	312.5
Initial Investment on Additional Rack (Baht)		-	4,200,000	4,320,000	4,440,000	4,560,000	4,800,000
Additional Rack (rack)		-	-	-	-	-	-
Estimated Cost per Rack (Bath)		70,000.00	120,000.00	120,000.00	120,000.00	120,000.00	120,000.00
Average Direct Saving Per Month (Baht/month)		5,514.89	11,620.06	12,259.18	15,565.93	15,565.93	15,565.93
Average Saving on Site Per Month (Baht/month)			16,597.22	15,763.89	17,152.78	17,152.78	17,152.78
Profit on Additional Throughput (Baht/month)		8,365.94	22,274.06	23,789.68	34,748.60	34,748.60	34,748.60
Total Return Per Month (Baht/month)		13,880.83	50,491.35	51,812.75	67,467.30	67,467.30	67,467.30
Payback Period (years)			7.00	7.00	5.50	5.67	6.00

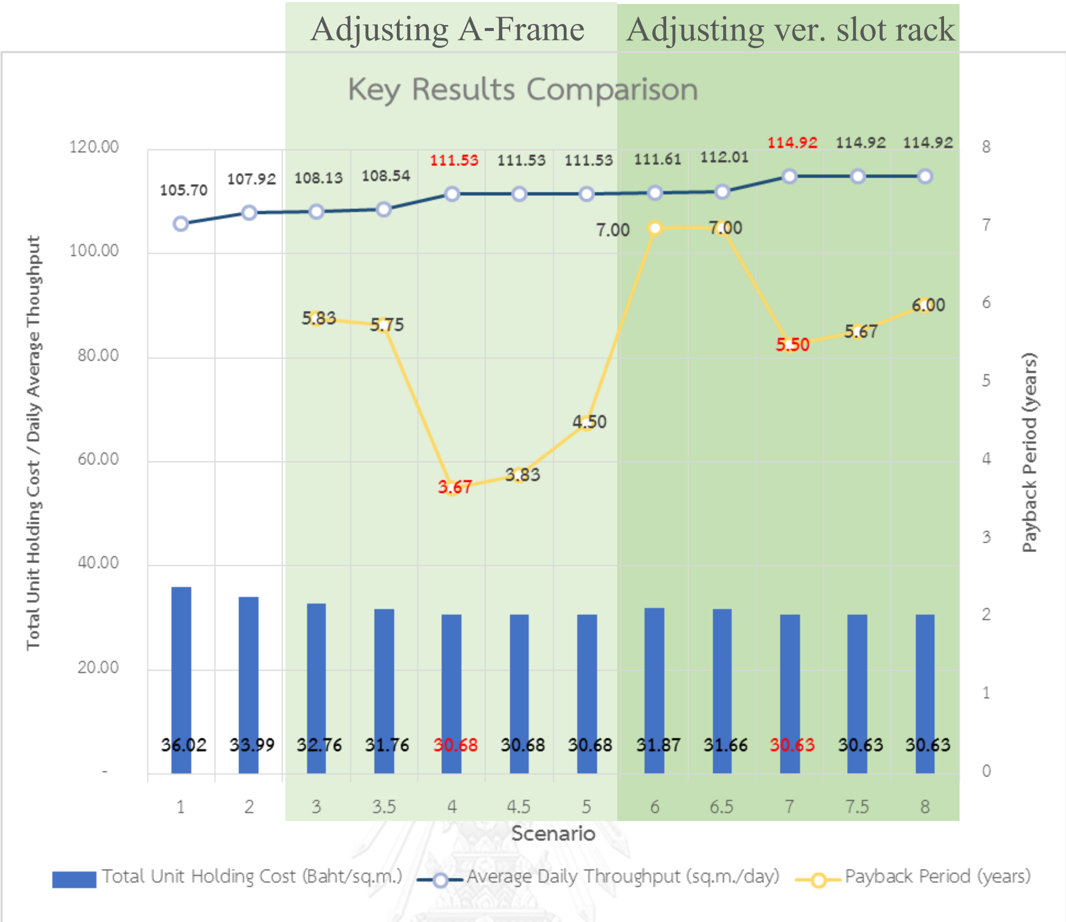


Figure 21 Key Results Comparison of Scenario 1-8

According to Figure 21, comparing results of using 40 A-Frame racks and 37 vertical slot racks, using vertical slot rack mainly improve average daily throughput because it eliminated process that decrease total lead time. Moreover, it has higher benefit to save on-site's cost. However, total holding cost per sq.m. are not significantly different because, refer to Exhibit 1, and Exhibit 5, total holding cost mainly come from fixed cost that are quite similar. Therefore, decrease in variable cost per sq.m. does not make a high amount to decrease total holding cost per sq.m. In financial perspective within the study's scope, scenario of 40 A-Frame racks (scenario 4) requires lower initial investment and shorter payback period in comparison to scenario of 37 vertical slot racks (scenario 7). Therefore, scenario of 40 A-Frame racks (scenario 4) is used as best practice and to perform sensitivity analysis with different demand patterns in the second part.

For the second part, refer to Table 26, as a result of best practice at total 40 racks, demand are varied at 3 patterns of high season to low season ratio, as follow

1. 65% to 35% for scenario 9, 12, and 15.
2. 50% to 50% for scenario 10, 13, and 16.
3. 35% to 65% for scenario 11, 14, and 17.

Moreover, types of rack are varied with different combination to results alternatively outcomes. Firstly, there are 17 moveable A-Frame rack in scenario 9, 10, and 11 to represent current performance. Secondly, there are additional 23 moveable A-Frame racks, or total 40 moveable A-Frame racks with improved sequence of stocking rack in scenario 12, 13, and 14 to represent improvement and benefit of using current type of rack. Lastly, there are 17 moveable A-Frame rack with additional 23 moveable vertical slot racks with improved sequence of stocking rack to represent alternative improvements and benefits of rack combination.

Refer to Table 26, it shows that current system with 17 moveable A-Frame tends to mainly operate on workflow case 2 in comparison to other scenarios with higher number of rack. It is because number of rack is insufficient to maintain throughput with operating on workflow case 1. However, due to high fixed cost in total holding cost, longer demand period in scenario 9 contributes to higher throughput of 121.80 sq.m./day and lower total holding cost per sq.m of 35.55 Baht/sq.m. in comparison to daily throughput of 94.25 and 84.19, and total holding cost per sq.m. of 37.86 and 38.82 Baht/sq.m. in scenario 10 and 11, respectively.

When number of A-Frame rack increases to 40 A-Frame racks, it will result in decrease in workflow case 2 and 3, and mainly operate on workflow case 1. It results that waste of handling each product to slot rack on outdoor stockyard, waiting for free A-Frame rack, double handling and arrange product onto free A-Frame rack on outdoor stockyard are mainly reduced from 87.86% to 46.77%, 71.94% to 21.19%, and 68.2% to 12.87% of total operating workflow in scenario 12, 13, and 14 respectively.

Refer to scenarios 12, 13, and 14 which have additional 23 moveable A-Frame racks, or at total 40 moveable A-Frame racks, in demand pattern ratio of 65% to 35%, 50% to 50%, and 35% to 65%, it boosts average daily throughput by 7.06%, 6.33%, and 5.62%, but decreases total holding cost by 12.75%, 12.15%, and 11.39% in comparison to scenarios with 17 moveable A-Frame racks, respectively. Moreover, it also requires initial investment of 1,610,000 Baht with payback periods of 2.92, 4.00, and 4.92 years in scenario 12, 13, and 14, respectively.

Table 26 Results of Scenario 9-17

	Demand 65 : 35	Demand 50 : 50	Demand 35 : 65	Demand 65 : 35	Demand 50 : 50	Demand 35 : 65	Demand 65 : 35	Demand 50 : 50	Demand 35 : 65
Detail	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16	Scenario 17
Operating Aspects									
% of Workflow Case 1	12.14%	28.06%	31.38%	53.23%	78.81%	87.13%	74.53%	94.57%	100.00%
% of Workflow Case 2	48.02%	46.77%	44.22%	26.51%	12.40%	7.17%	17.37%	3.67%	0.00%
% of Workflow Case 3	39.84%	25.16%	24.40%	20.26%	8.79%	5.70%	8.10%	1.76%	0.00%
Sequence of Stocking Rack in Outdoor Stockyard	Current	Current	Current	Improved	Improved	Improved	Improved	Improved	Improved
Type of Rack	A-Frame	A-Frame	A-Frame	A-Frame	A-Frame	A-Frame	Both	Both	Both
Number of A-Frame Rack	17	17	17	40	40	40	17	17	17
Number of Ver. Slot Rack							23	23	23
Number of Using Ver. Slot Rack							682	500	465
Benchmark scenario				9	10	11	9	10	11
Average Daily Throughput (sq.m./day)	**121.80**	**94.25**	**84.19**	**130.40**	**100.21**	**88.93**	**132.94**	**101.92**	**89.97**
% Increase				**7.06%**	**6.33%**	**5.62%**	**9.15%**	**8.14%**	**6.86%**
Total Holding Cost/Output (Baht/sq.m.)	**35.55**	**37.86**	**38.82**	**31.01**	**33.27**	**34.40**	**30.39**	**32.53**	**33.67**
% Decrease				**-12.75%**	**-12.15%**	**-11.39%**	**-14.51%**	**-14.08%**	**-13.29%**
Financial Aspect									
Estimated Profit of Wall Panel (Baht/sq.m.)	150	150	150	150	150	150	150	150	150
Estimated Saving from Using Ver. Slot Rack (Baht/rack)							312.5	312.5	312.5
Initial Investment on Additional Rack (Baht)				1,610,000	1,610,000	1,610,000	2,760,000	2,760,000	2,760,000
Additional Rack (rack)	0	-	-	23	23	23	23	23	23
Estimated Cost per Rack (Bath)	70,000	70,000	70,000	70,000	70,000	70,000	120,000	120,000	120,000
Average Direct				14,830.48	11,560.53	9,860.09	17,205.55	13,632.62	11,639.89
Average Saving on							17,760.42	13,020.83	12,109.38
Profit on				32,349.67	22,455.41	17,813.81	41,933.37	28,866.38	21,720.03
Total Return Per Month (Baht/month)				47,180.16	34,015.94	27,673.90	76,899.34	55,519.83	45,469.30
Payback Period (years)				**2.92**	**4.00**	**4.92**	**3.00**	**4.17**	**5.08**

Furthermore, in alternative of increase 23 vertical slot rack instead of A-Frame racks, it will result in decrease in workflow case 2 and 3, and mainly operate on workflow case 1. It results that waste of handling each product to slot rack on outdoor stockyard, waiting for free A-Frame rack, double handling and arrange product onto free A-Frame rack on outdoor stockyard are mainly reduced from 87.86% to 12.87%, 71.94% to 5.43%, and 68.2% to 0.00% of total operating workflow in scenario 12, 13, and 14 respectively.

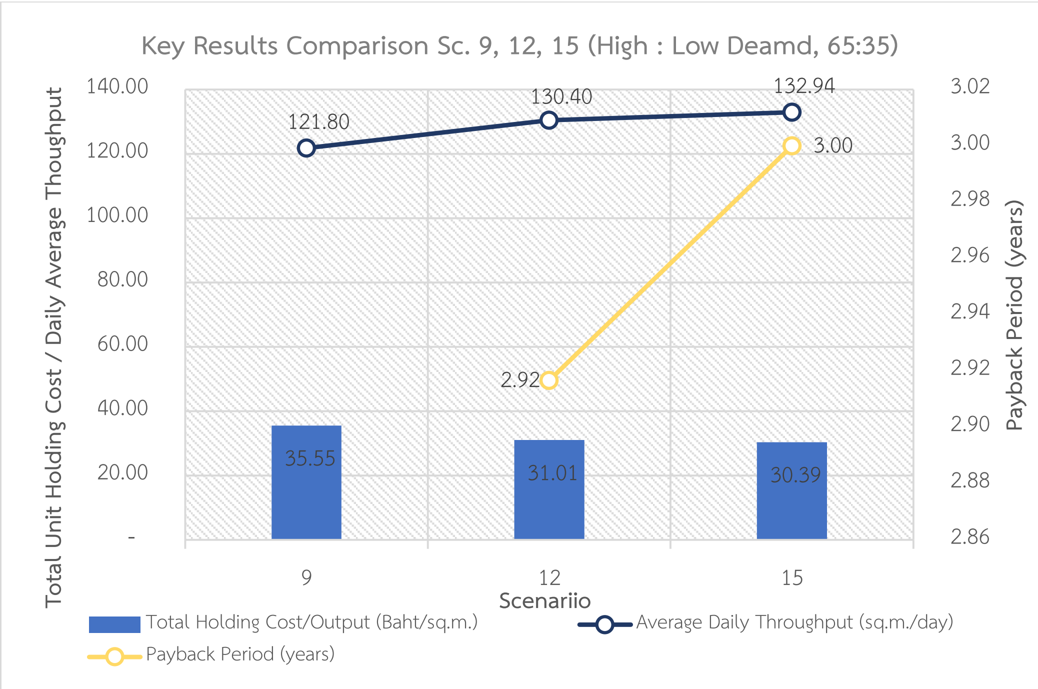


Figure 22 Key Results Comparison in Demand Pattern Ratio 65: 35 (High: Low Season) of Scenario 9, 12, 15

Refer to scenarios 15, 16, and 17 which have 17 moveable A-Frame racks and additional 23 moveable vertical slot racks, in demand pattern ratio of 65% to 35%, 50% to 50%, and 35% to 65%, it boosts average daily throughput by 9.15%, 8.14%, and 6.86%, while decreases total unit holding cost by 14.51%, 14.08%, and 13.29% in comparison to scenarios with 17 moveable A-Frame racks scenarios. Moreover, it requires initial investment of 2,760,000 Baht with payback periods of 3.00, 4.17, and 5.08 years, respectively. Even though implementing moveable vertical slot racks requires higher investment than investing in additional moveable A-Frame rack by 1.15

million Baht, it eliminates constraint of number of difficult wall panel in arranging process. Moreover, it provides additional benefit on reducing on-site cost which reduces 15 minutes of unloading time per rack on site work.

Refer to Figure 22, 23, and 24, they show key results comparison in perspective of each demand pattern ratio. Firstly, refer to Figure 22, under high season to low season demand pattern ratio 65% to 35%, implementing additional 23 moveable A-Frame racks, or total 40 moveable A-Frame racks increase average daily throughput by 7.06% from 121.80 to 130.40 sq.m./day, and decrease total unit holding cost by 12.75% from 35.55 to 31.01 Baht/sq.m. in comparison to scenario 9 (using 17 moveable A-Frame racks scenario). It requires initial investment of 1,610,000 Baht with payback period 2.92 years. However, implementing additional 23 moveable vertical slot racks with current total 17 moveable A-Frame racks increases average daily throughput by 9.15% from 121.80 to 132.94 sq.m./day, and decrease total unit holding cost by 14.51% from 35.55 to 30.39 Baht/sq.m scenario 9 (using 17 moveable A-Frame racks scenario). Lastly, it requires initial investment of 2,760,000 Baht with payback period 3.00 years.

Secondly, refer to Figure 23, under high season to low season demand pattern ratio 50% to 50%, implementing additional 23 moveable A-Frame racks, or total 40 moveable A-Frame racks increase average daily throughput by 6.33% from 94.25 to 100.21 sq.m./day, and decrease total unit holding cost by 12.15% from 37.86 to 33.27 Baht/sq.m. in comparison to scenario 10 (using 17 moveable A-Frame racks scenario). It requires initial investment of 1,610,000 Baht with payback period 4.00 years. However, implementing additional 23 moveable vertical slot racks with current total 17 moveable A-Frame racks increases average daily throughput by 8.14% from 94.25 to 101.92 sq.m./day, and decrease total unit holding cost by 14.08% from 37.86 to 32.53 Baht/sq.m scenario 10 (using 17 moveable A-Frame racks scenario). Lastly, it requires initial investment of 2,760,000 Baht with payback period 4.17 years.

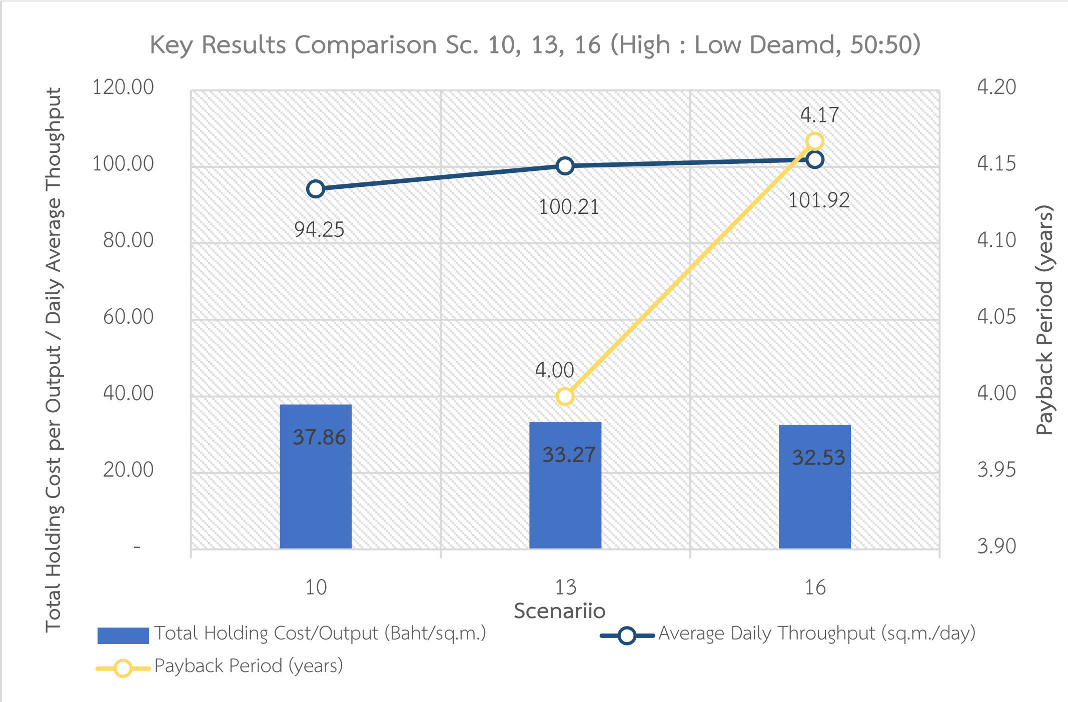


Figure 23 Key Results Comparison in Demand Pattern Ratio 50: 50 (High: Low Season) of Scenario 11, 13, 16

Thirdly, refer to Figure 24, under high season to low season demand pattern ratio 35% to 65%, implementing additional 23 moveable A-Frame racks, or total 40 moveable A-Frame racks increase average daily throughput by 5.62% from 84.19 to 88.93 sq.m./day, and decrease total unit holding cost by 11.39% from 38.82 to 34.40 Baht/sq.m. in comparison to scenario 11 (using 17 moveable A-Frame racks scenario). It requires initial investment of 1,610,000 Baht with payback period 4.92 years. However, implementing additional 23 moveable vertical slot racks with current total 17 moveable A-Frame racks increases average daily throughput by 6.86% from 84.19 to 89.97 sq.m./day, and decrease total unit holding cost by 13.29% from 38.82 to 33.67 Baht/sq.m scenario 11 (using 17 moveable A-Frame racks scenario). Lastly, it requires initial investment of 2,760,000 Baht with payback period 4.17 years.

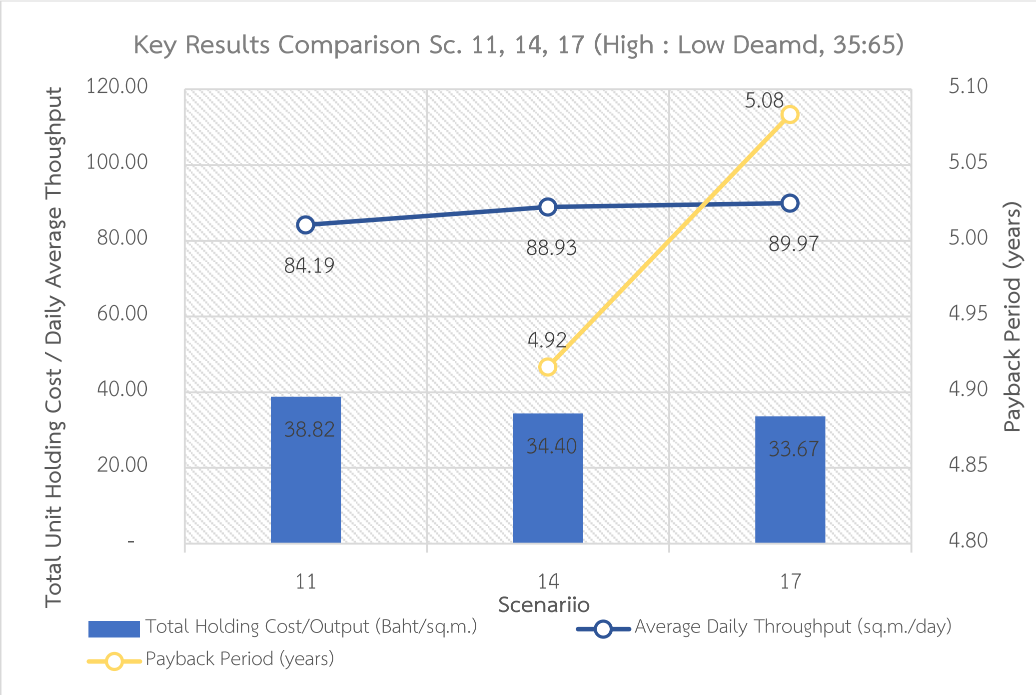


Figure 24 Key Results Comparison in Demand Pattern Ratio 35: 65 (High: Low Season) of Scenario 12, 14, 17

Consequently, from these perspectives, it could be concluded that increase in demand generates a higher profit and cost reduction as operating outcome as well as reduces payback period. Moreover, even though initial investment for 23 moveable vertical slot racks is higher than initial investment for 23 moveable A-Frame slot racks at 1,150,000 Baht, it has an additional benefit for cost deduction on site work that potentially shortens payback period. Differences between implementing additional 23 moveable A-Frame racks and 23 moveable vertical slot racks is 2.86%, 4.17%, and 3.39% for high to low demand pattern ratio of 65% to 35%, 50% to 50%, 35% to 65%, respectively.

10. Conclusion and Recommendations

10.1. Summary

Due to Thailand's construction industry has turned to implement precast concrete system to improve their efficiency, and most of them focus on production line's efficiency, several efficiency problematic issues arise in post-production stage which related to handling process that reduce overall efficiency. In this research, an operating precast concrete factory in Thailand is used as a case study to investigate problematic issues, and suggest possible alternative solutions. The main research's purpose is to design handling process in post-production stage for precast concrete manufacturer to serve several levels of system's throughput, or market demand patterns.

The factory's working areas are separated into 2 main areas which are indoor stockyard area, and outdoor stockyard area. Current processes start from handling to tilting station, QC station, and arranging wall panel into A-Frame rack in indoor stockyard, then packaged wall panels in A-Frame rack are transferred into outdoor stockyard area, and handled onto truck on delivery day.

After gathering necessary information, wastes in the system are defined and leads to their root causes. Current problems are stated that the factory has to increase additional processes, especially in handling process which extends workflow to be longer to balance, and serve a higher throughput level in high seasonal demand. The main root cause of existing problematic issues are lacking of moveable A-Frame that causes additional handling processes in the system. To find alternative solutions and measure outcomes, simulation model is constructed, and validated accordance with actual collected data. To measure the outcomes, it separates into 2 main aspects which are operating aspect, and financial aspect. Operating aspect includes average daily throughput total holding cost per unit, and financial aspect includes initial investment, and payback period.

Based on validated simulation model results, it is found that sequence of stocking packaged racks can be improved immediately without any initial cost.

Furthermore, total numbers of 40 moveable A-Frame with improved sequence of stocking packaged racks results the best operating outcomes for current demand. Average daily throughput increases 5.52%, and total unit holding cost decreases 14.84%. Even operating outcomes are quite similar in scenario 4, and 7, total numbers of 40 moveable A-Frame racks in scenario 4 requires significantly lower initial investment at 3.67 years than total number 40 moveable vertical slot racks in scenario 7 at payback period 8 years. It is because it requires only 23 additional A-Frame racks in scenario 4, while it requires all 40 additional moveable vertical slot racks in scenario 7.

In addition, increase number of rack overs 40 moveable racks does not improve any operating outcome, but increase initial investment, and payback period. Moreover, with the best practice in different demand patterns, operating handling process in a longer high demand season, operating and financial performances perform a better outcomes than operating handling process in a shorter low demand period. Even though moveable vertical slot rack requires higher initial investment, it provides additional benefit over moveable A-Frame rack in order to reduce cost on site-work in every use of moveable vertical slot rack.

10.2. Research Limitations

1.) Confidential Company's Information

Some deep informations are not available for publication, such as financial information, and actual costs. Hence, calculating and estimating cost in this research are estimated based on available information and other public sources, and cannot be directly verified with actual cost publicly.

2.) Limitation of Historical Data

Because it is a new established factory less than 5 years, data collection is still limited. Data collection in post-production stage has started for 9 months before the research started. Hence, it has only useful 9 months historical data for performing the simulation model. Even it is enough for completing the research well, higher amount of data collection will increase model's precision.

10.3. Recommendations

To improve current system of precast concrete factory, it is difficult to examine alternative experiments to find solutions. Validated simulation model is a potential tool for examine those experiments with lower cost. With this concept, it can be extended along its supply chain, and integrated with optimization model.

According to a validated simulation model for precast concrete wall panel, the model can be usefully extended to other structural element products, such as precast concrete slab, beam, column, and stair, and non-structural element products, such as precast concrete pipe. Furthermore, the model can be developed to integrate with other programs to simplify inputting various data, insert optimization algorithm, and illustrate graphically outputs. Hence, the developed model can be used for more precise forecasting than current version. Finally, the model can be developed, and generalized as a common program for every precast concrete factory that will benefit in order to monitor, control, and improve current system.

REFERENCES

Dawood, N. and Marasini, R. (2000). A Simulation Model to Manage and Optimise Stockyard Layout: a Case Study in Precast Concrete Products Industry. 16th Annual ARCOM Conference, Glasgow Caledonian University, 6-8 September 2000. A. A. Akintoye. 2: 527-536.

Dawood, N. and Marasini, R. (2003). "Visualisation of a Stockyard Layout Simulator “SimStock”: a Case Study in Precast Concrete Products Industry." Automation in Construction 12(2): 113-122.

Dawood, N. N. (1995). "An integrated knowledge-based/simulation approach to production planning: an application to the pre-cast industry." Construction Management and Economics 13(1): 53-64.

Deffense, J. and Cachadinha, N. (2011). Lean Production in the Precast Concrete Components’ Industry. IGLC-19, Lima, Perú.

Ebawe Anlagentechnik GmbH (2016). "Complete Solution From a Single Source." Available from http://www.ebawe.com/en/complete-solutions-single-source. [25th September 2016]

Elematic Oy Ab. (2010). "Growing Precast Market in Asia." Available from http://www.concreteissues.com/en/stories/1-10/growing-precast-market-in-asia. [18th September 2016]

Elliott, K. S. (2002). Precast Concrete Structures. Great Britain, Elsevier.

Ishibuchi, H. and Murata, T. (1998). A Multi-Objective Genetic Local Search Algorithm and Its Application to Flowshop Scheduling. IEEE Transactions on Systems, Man, and Cybernetics, IEEE. 28: 392 - 403.

Ko, C. H. (2010). "An Integrated Framework for Reducing Precast Fabrication Inventory." Journal of Civil Engineering and Management 16 (3): 418-427.

Marasini, R. and Dawood, N. (2002). Simulation modeling and optimization of stockyard layouts for precast concrete products. Simulation Conference, 2002. Proceedings of the Winter, IEEE.

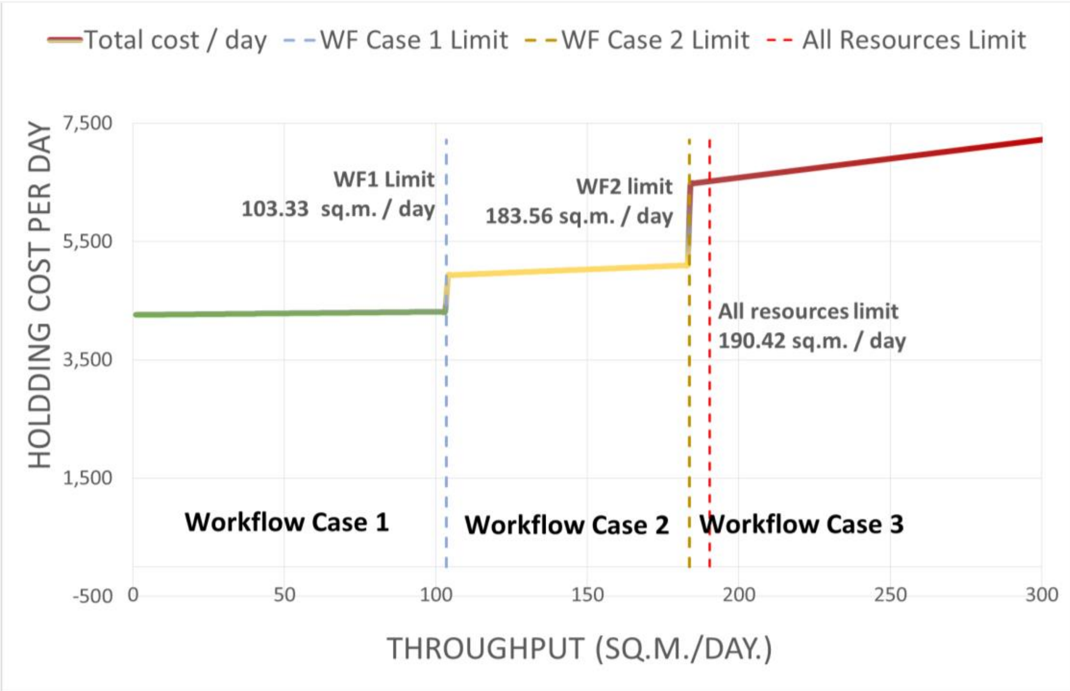
Marasini, R., et al. (2001). "Stockyard layout planning in precast concrete products industry: a case study and proposed framework." Construction Management and Economics 19(4): 365-377.

Tanompandseree, N. (2006). Analysis of Precast Concrete Element Management Process in Housing Projects Using Case Studies. Faculty of Engineering, Chlulaongkorn Unversity. Master of Engineering Program in Civil Engineering.

Waroonkun, T. and Koojaroenpaisan, R. (2011). Modelling of Factor Impacting Adoption of Precast Concrete System. Management and Innovation for a Sustainable Built Environment 20-23 June 2011. Amsterdam, The Netherlands.

APPENDIX

Exhibit 1 Total Holding Cost Equation in Case of using 40 A-Frame Racks



$x \leq 103.33;$ $\quad y = 0.5235x + 4261.7 \quad (4)$

$103.33 < x \leq 183.56;$ $\quad y = 2.1104x + 4711.4 \quad (5)$

$x > 183.56;$ $\quad y = 6.4000x + 5296.3 \quad (6)$

Where x is daily throughput (sq.m./day), and y is total holding cost per day (Baht/day).

Exhibit 2 Workflow of Handling Process Case 1 in Case of using Vertical Slot Rack

Indoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P
Activity	Handle product from tilting table to QC station	Wait for QC	QC checking and examining	Decide consequence of wall panel on rack	Handle, and arrange product onto A-Frame rack on transfer car
Time (minute/piece)	5.46	10.06	15.00	7.24	5.37

(50% of total input required examining)

Outdoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P	P
Activity	Move transferring car to outdoor area	Wait for Crane 20t and Operator Gr. 2	Handle arranged A-Frame rack to stockyard	Wait for truck that align with erection plan	Handle arranged A-Frame rack onto truck	Full-loaded truck travel to site
Time Time (minute/rack)	1.00	6.12	7.42	98.54	8.84	Depend on location

Exhibit 3 Workflow of Handling Process Case 2 in Case of using Vertical Slot Rack

Indoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P
Activity	Handle product from tilting table to QC	Wait for QC	QC checking and examining	Decide consequence of wall panel on rack	Handle, and arrange product onto A-Frame rack on transfer
Time (minute/piece)	5.46	10.06	15.00	7.24	5.37

(50% of total input required examining)

Outdoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P	W	P	P
Activity	Move transferring car to	Wait for Crane 20t and	Handle each product to slot rack on	Wait for free A-Frame rack	Handle and arrange product onto free A-	Wait for truck that align with erection plan	Handle arranged A-Frame rack	Full-loaded truck travel to site
Time (minute/rack)	1.00	6.12	58.76	720.00	139.66	98.54	8.84	Depend on location

Exhibit 4 Workflow of Handling Process Case 3 in Case of using Vertical Slot Rack

Indoor Stockyard

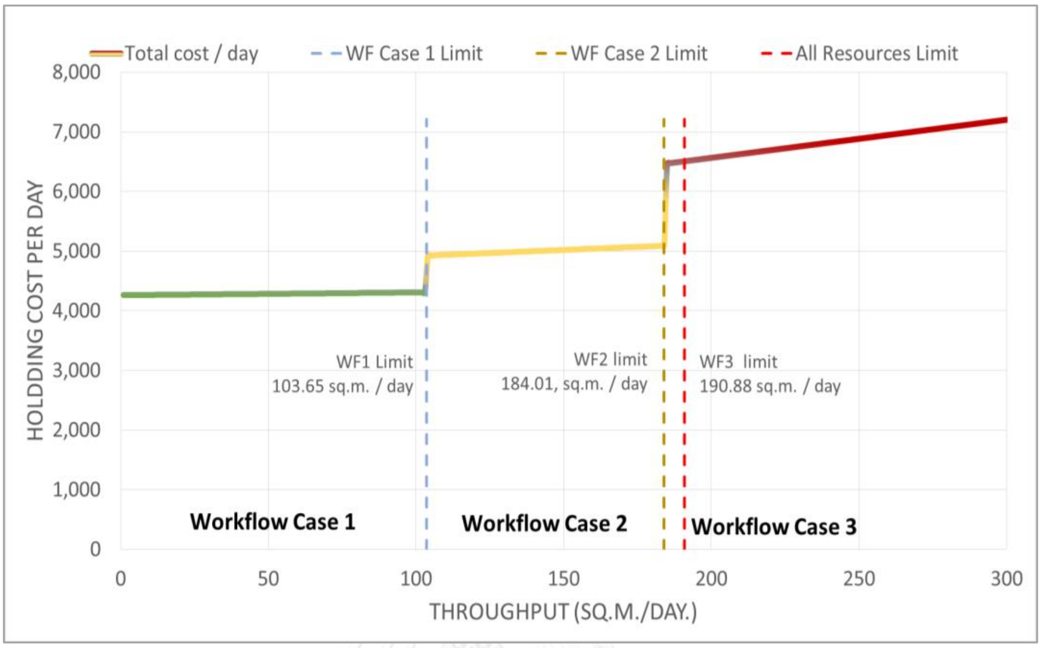
	In case: QC station is full of WIP products and new product is coming				In case: QC station is full of finished products and new product is coming		
Type of Work (P=Processing, W = Waiting)	P	P	W	P	P	W	P
Activity	Handle product from tilting table to free slot	Handle to QC station	Wait for QC	QC checking and examining	Handle product to free slot	Wait for proper queue on A-Frame rack.	Handle unarranged product onto A-Frame rack on transfer car
Time (minute/piece)	5.46	5.46	10.06	15.00	5.46	7.24	5.37

(50% of total input required examining)

Outdoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P	W	P	P
Activity	Move transferring car to outdoor area	Wait for Crane 20t and Operator Gr. 2	Handle each product to slot rack on stockyard	Wait for free A-Frame rack	Handle and arrange product onto free A-Frame rack	Wait for truck that align with erection plan	Handle arranged A-Frame rack onto truck	Full-loaded truck travel to site
Time (minute/rack)	1.00	6.12	58.76	720.00	139.66	98.54	8.84	Depend on location

Exhibit 5 Total Holding Cost Equation in Case of using Vertical Slot Rack



$x \leq 103.65;$ $\quad y = 0.4581x + 4261.7$ (7)

$103.65 < x \leq 184.01;$ $\quad y = 2.0595x + 4711.7$ (8)

$x > 184.01;$ $\quad y = 6.4000x + 5284.6$ (9)

Where x is daily throughput (sq.m./day), and y is total holding cost per day (Baht/day).

Exhibit 6 Workflow of Handling Process Case 1 in Case of using 17 A-Frame and 23 Vertical Slot Rack

Indoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P
Activity	Handle product from tilting table to QC station	Wait for QC	QC checking and examining	Decide consequence of wall panel on rack	Handle, and arrange product onto A-Frame rack on transfer car
Time	5.42	10.32	14.89	9.49	5.71

(50% of total input required examining)

Outdoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P	P
Activity	Move transferring car to outdoor area	Wait for Crane 20t and Operator Gr. 2	Handle arranged A-Frame rack to stockyard	Wait for truck that align with erection plan	Handle arranged A-Frame rack onto truck	Full-loaded truck travel to site
Time Time (minute/rack)	1.00	8.53	6.93	108.93	8.73	Depend on location

Exhibit 7 Workflow of Handling Process Case 2 in Case of using 17 A-Frame and 23 Vertical Slot Rack

Indoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P
Activity	Handle product from tilting table to QC station	Wait for QC	QC checking and examining	Decide consequence of wall panel on rack	Handle, and arrange product onto A-Frame rack on transfer car
Time (minute/piece)	5.42	10.32	14.89	9.49	5.71

(50% of total input required examining)

Outdoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P	W	P	P
Activity	Move transferring car to outdoor area	Wait for Crane 20t and Operator Gr. 2	Handle each product to slot rack on stockyard	Wait for free A-Frame rack	Handle and arrange product onto free A-Frame rack	Wait for truck that align with erection plan	Handle arranged A-Frame rack onto truck	Full-loaded truck travel to site
Time (minute/rack)	1.00	8.53	50.38	720.00	143.14	108.93	8.73	Depend on location

Exhibit 8 Workflow of Handling Process Case 3 in Case of using 17 A-Frame and 23 Vertical Slot Rack

Indoor Stockyard

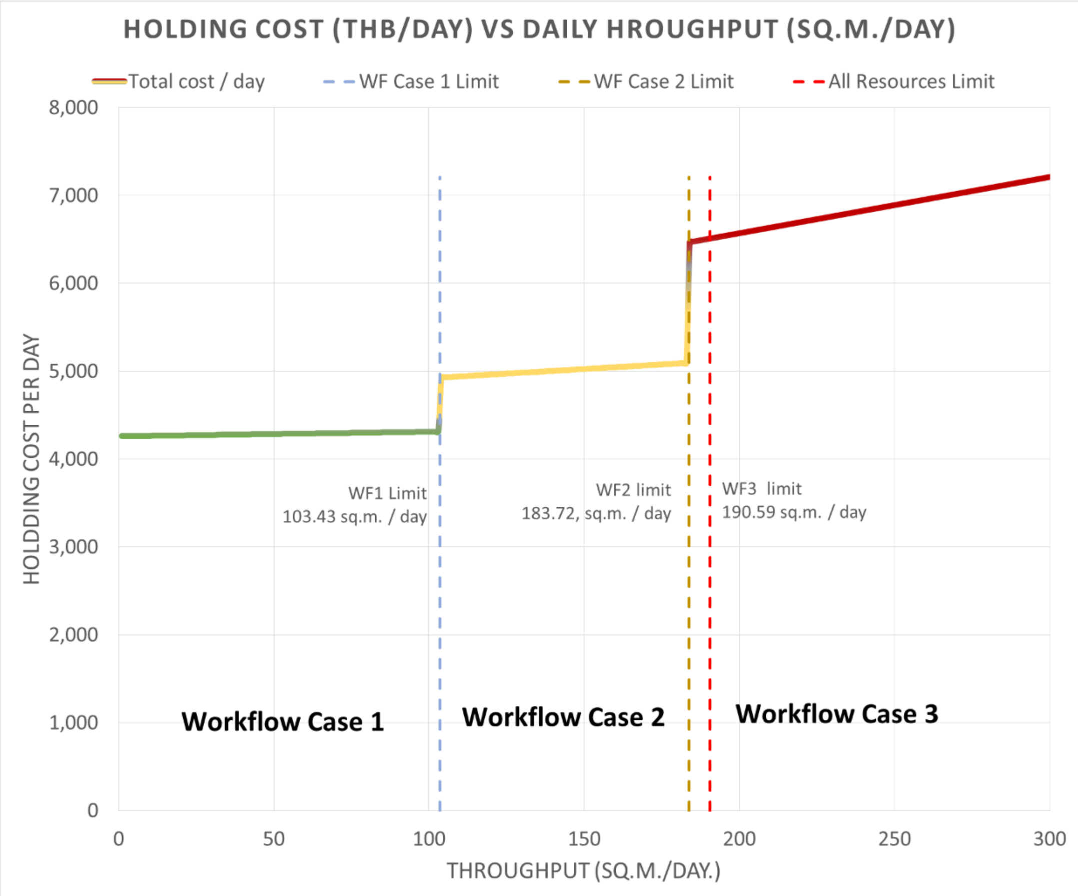
	In case: QC station is full of WIP products and new product is				In case: QC station is full of finished products and new		
Type of Work (P=Processing, W = Waiting)	P	P	W	P	P	W	P
Activity	Handle product from tilting table to free slot	Handle to QC station	Wait for QC	QC checking and examining	Handle product to free slot	Wait for proper queue on A-Frame rack.	Handle unarranged product onto A-Frame rack on transfer car
Time (minute/piece)	5.41	5.42	10.32	14.89	5.41	9.49	5.71

(50% of total input required examining)

Outdoor Stockyard

Type of Work (P=Processing, W = Waiting)	P	W	P	W	P	W	P	P
Activity	Move transferring car to outdoor area	Wait for Crane 20t and Operator Gr. 2	Handle each product to slot rack on stockyard	Wait for free A-Frame rack	Handle and arrange product onto free A-Frame rack	Wait for truck that align with erection plan	Handle arranged A-Frame rack onto truck	Full-loaded truck travel to site
Time (minute/rack)	1.00	8.53	50.38	720.00	143.14	108.93	8.73	Depend on location

Exhibit 9 Total Holding Cost Equation in Case of using 17 A-Frame and 23 Vertical Slot Rack



$x \leq 103.43;$ $y = 0.5014x + 4261.7$ (10)

$103.43 < x \leq 183.72;$ $y = 2.0974x + 4711.7$ (11)

$x > 183.72;$ $y = 6.4000x + 5290.97$ (12)

Where x is daily throughput (sq.m./day), and y is total holding cost per day (Baht/day).

VITA