JOB SCHEDULING AND PACKING OPTIMIZATION IN WAREHOUSE: ON-TIME ORDER DELIVERY AND INCENTIVE FOR FULL-PACK ORDER

BY

MR. JIRAKRIT SASANARAKKIJ

AN INDEPENDENT STUDY SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS ENGINEERING)

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ENTITLED

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ABSTRACT

The responsiveness of the company depends on many factors, and, in the warehouse, order scheduling and inventory handling cost are two of the most important factors. According to the fact that changes in warehouse operation have some risks and investment, the optimization model aims to minimize the make span of the orders in the warehouse to support the decision making while also to see the feasibility. Moreover, there is a waste in the operation when the order does not come in a batch or packed size, thus, the workers need to unpack and repack again. Therefore, this project aims to help the warehouse to have more responsiveness and minimize the cost from the waste by efficiently scheduling the orders and giving a suitable incentive to the customers when ordering in a full pack. The method of approach used is proposing the model with an optimization in IBM ILOG CPLEX software. The result is the model that can be used to solve the order scheduling and to indicate a suitable incentive for the full-pack order.

Keywords: Warehouse, Job scheduling, Optimization, Deadline, Unpack and Repack, Two-echelon supply chain

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Mr. Jirakrit Sasanarakkij

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CHAPTER 1
INTRODUCTION

Nowadays, the competitive abilities of the company depend on globalization, rapid market changes, high productivity, and reduction of time-to-market impacts significantly. Therefore, planning and organizing the warehouse have become a more impactful and interesting factor to be considered.

In warehouses, the common problem is an order scheduling problem. This problem occurs from an ineffective schedule order picking based on the deadline. This leads to the delay of delivering the products to the customers, thus, the customer's satisfaction is relatively low. Another problem of organizing the warehouse is the waste from unpacking and repacking the order due to a partial-unit order.

In this paper, an opportunity to participate in the warehouse operation improvement has been given, we decide to propose a mixed-integer linear programming (MILP) optimization model with multiple objectives. The first objective of the model is to effectively schedule order and the second objective is to find the optimal incentive for the full-pack order.

1.1 Problem statement

The problems that are concerned in this paper are the order scheduling and the waste from repacking operations. When order scheduling is not assigned efficiently, a delay occurs. This directly affects the company's reputation and customer satisfaction. While the unpack and unpack operations lead to unnecessary cost or waste. This problem arises when the order's quantity does not match with the full-pack amount in the warehouse. The solution suggested is to give a promotion or the incentive to the full-pack order. This is the trade-off between the cost from the pack and unpack operation and the promotion that gives to the full-pack order.

1.2 Objectives of the study

This project is mainly about proposing the optimization model as a tool for improving the warehouse performance in the paint coating industry. Thus, the project aims to:

1. To develop a model considering the job scheduling and repacking process with a real case study.
2. To recommend suitable order scheduling and repacking operation to optimize the cost of two-echelon supply chain.

CHAPTER 2
REVIEW OF LITERATURE

This chapter consists of two parts. The first part is general knowledge of this project which provides the definition of technical terms and theories involved in the project. The next part is the related literature. This part covers the literature review related to the project.

2.1 General knowledge

This part provides the technical knowledge and theories that are related to this project. The objective is to make the reader get insight into the tools and theories for more understanding.

2.1.1 Nature of two-echelon supply chain

In the two-echelon supply chain, there will be a supplier (wholesaler) and a customer (retailer) which will be called as a seller and a buyer in this paper. And in the normal operation of the warehouse, there can be two scenarios according to the unpacking and repacking operations.

The first scenario is when there is an unpacking and repacking operation. In this case, when the order comes as a partial batch that the seller is keeping, the seller has to unpack to get the exact amount that the buyer needs and then repack them again to deliver to the buyer. Therefore, the buyer will get the exact amount that they need or the right amount for their demand meaning that they do not have excess units that have to be stored in the warehouse. So, they will have a cost saving of the holding cost in this case, but the seller has to do the unpacking and repacking operation that is time and cost consuming, moreover, this might lead to the tardy of an order as the operation time is increased.

The second scenario is when the order comes into full batch as the warehouse is keeping. In this case, the seller does not have to do the unpack and repack operation and can deliver the order right to the buyer. But there is a case that the seller has more bargaining power or has a policy to strict the order quantity as full batch only as well. In such a case, the buyer will have to hold the excess unit from their actual demand.

For example, the demand of the buyer (retailer) is 70 units, but the full batch that the seller keeps in the warehouse is 100 units and they only allow orders in full batch. Thus, the buyer will get 30 units more than their actual demand and have to keep the rest in the inventory and pay for the holding cost. In short, the seller will save the unpack and repack cost and the time needed to do those operations, but the buyer will have to pay the holding cost of the excess units.

In conclusion, the cost that occurs at the wholesaler (Seller) is the Unpacking and Repacking cost, and the tardy cost when the order is being delivered late. While the cost at the retailer (Buyer) is the holding cost when they get the excess units apart from their actual demand.

2.1.2 Optimization approach

Optimization is a scientific approach developed and publicized by G. Dantzig (1963). It is a technique that seeks to find combinations of variables (decision variables) that yields the best possible value of the objective function(s) under a set of constraints. Its applications emerge in various fields to find the most suitable outcome or maximize or minimize the factors in order to gain the best result. For example, in airline industry, this method is used to calculate the best number of passengers per flight, or the amount of fuel used so that the company could save cost and yield higher profit. On the other hands, in manufacturing fields, how much labor cost should be minimized or how much time should be used to maximize the manufacturing process. Overall, this method gives the best possible outcome under constraints for the factory.

There are various types of techniques being applied under the optimization approach. WSP is frequently formulated with linear integer programming (LIP), binary integer programming (BIP), or mixed-integer linear programming (MILP) as conventional techniques. Among those method, this paper uses mixed-integer linear programming (MILP) as the main tools under Program CPLEX Optimizer. This optimizer provides high-performance mathematical programming solvers which one of them is MILP. This tool is useful and has been utilized in various number of academic papers in different field. The author, Malinee Wongruean (2009), uses MILP to determine the optimal resource allocation and solve the automatic workload leveling problem in petroleum company. In order to determine the annual operational strategy, the research from Antonio Costa & Alberto Fichera (2014) applied the optimal method using MILP in their research to evaluate the CHP system under hospital structures. Moreover, Mohammadreza Radmanesh & Manish Kumar (2015) employ MILP to propose a cost function that minimizes both time and energy consumption of each airline flight. Alternatively, a study in hybrid power system containing thermal, hydro, and wind power by Bo Fu, Chenxi Ouyang, Chaoshun Li, Jinwen Wang and Eid Gul (2019) has also proposed the MILP approach to solve the unit commitment problem.

This paper has applied mixed-integer linear programming (MILP) using Program C-Plex to improve order scheduling of warehouse. This method has been utilized by various academic research in order to find the optimal result for scheduling problem. Scheduling is measured as the major element of the efficient operation process not only in industry level but also other field or smaller scale process. The paper of Christodoulos A. Floudas and Xiaoxia Lin (2005) utilize advanced MILP for the scheduling of chemical processing systems which mainly focuses on the short-term processes. As mentioned in previous paragraph, this approach can also be applied in hospital system. The research from Karsten Schwarz, Michael Römer & Taïeb Mellouli (2019) applied this method to the real-world case using real data from German University hospital. They aimed to improve the day-level scheduling of clinical pathways under the consideration of all relevant resources such as clinical staff, beds, operating rooms etc. On the other hands, this technique is employed to cope with the scheduling problem of automotive plastic components, production process of injection molds, and lot sizing. This recent paper aims to minimize the setup, inventory, stockout and backorder costs of injection model (Beatriz Andres, Eduardo Guzman and Raul Poler, 2021). All these cited papers are in different areas, however, they all gained practically and theoretically the efficient and optimal results for the scheduling problems in their own expertise.

2.2 Related literature

Nowadays, the warehouse operation has become one of the main issues concerned as demonstrated by Aboelfotoh, Singh, and Suer (2019). Dotoli, Epicoco, Falagario, Costantino, and Turchiano (2015) also showed solid evidence that the optimization and analysis in the warehouse have an impact far wider than in the past on the competitive ability of the company or business.

Zhang, Lin, Huang, and Hu (2019) stated that the online market has rapidly grown in recent years, therefore, order splitting has become a great challenge to online retailers for fulfilling multi-item orders in a multi-warehouse storage network. Therefore, they use an enhanced logic-based Benders' decomposition algorithm to propose an optimization model to reduce the total costs, the number of packages, and the delivery times. Weidinger, Boysen, and Schneider (2018) also said that e-commerce has become booming and e-commerce deals with the difficulty to assemble large numbers of time-critical picking orders. These facts prove that the warehouse organization has been a very important factor.

Warehouse responsiveness is also one of the main concerns in the customer's perspective and customer expectation tends to increase over time, as demonstrated by Kim (2018). The warehouse responsiveness problem is mostly raised from the order or job scheduling inefficiently. Thus, the researchers give a lot of effort to solve this commonly found problem. Moeller (2011) said that the travel time covers a substantial part of picking processes in warehouses, therefore, the job and route scheduling are crucial to be high efficiency. For the analysis of the performance of job scheduling, Krishnaveni, and Hemalatha (2012) stated that the particle swarm optimization algorithm along with the simulated annealing algorithm is suggested. There is a lot of research that is concerning the total travel distance in the warehouse. The first paper by Yang, Zhao, and Guo (2020) told the importance of minimizing the total picking distance in the warehouse, especially in e-commerce companies. The second one is demonstrated by Chung, Lee, and Yoon (2020) that the correlated storage assignment strategy links to the improvement of warehouse order picking operations efficiency. Next, Ang and Lim (2019) studied the optimization of storage classes while the total travel cost is minimized. Also, Kordos, Boryczko, Blachnik, and Golak (2020) performed the solution using genetic algorithms for the optimization of discrete product placement and of order picking routes in a warehouse. Lastly, the metaheuristic optimization is one of the most powerful and high potential to solve the order picking problem along with other objectives such as storage location as studied by Silva, Coelho, Darvish, and Renaud (2020). These papers show how the optimization in the warehouse of some relative factors is important and there are many potential algorithms that can be applied in the problem.

Apart from the scheduling problem, the problem that highly affects the responsiveness of the company is the logistics and supply chain problem. Luo, Yang, and Wang (2019) stated that being a very competitive supply chain is important in recent years and also some strategies should be applied such as changing from traditional make-to-stock to make-to-order to reduce the inventory cost and the cross-docking strategy. These strategies, especially cross-docking, have been a topic of interest in the past 10 years. Yu, and Egbelu (2008) and Boysen, and Fliedner (2010) proved that the cross-docking strategy is one of the potential tools in the warehouse strategy. This strategy also reduces the product unit costs delivered as proven by Mavi et al. (2020).

Although there are many types of research in the field of warehouse optimization on job/order scheduling with deadline constraint and pack and unpack problems, our project covers a new and specific case that use the real data collected from the warehouse of paint and coating products. It covers the topics of the pack and unpack problem and order scheduling with deadline constraint as shown in Table 2.1 below.

Table 2.1 Fields of the literatures

Article No.	Article title	Publication year	No. of citations	Ware-house	Optmi-zation	Job scheduling	Deadline	Repack/ Unpack	Multi-objective	Cross docking	Picker routing	Logi-stics
1	Scheduling of inbound and outbound trucks in cross docking systems with temporary storage	2008	13	✓	✓	✓			✓	✓		✓
2	Cross dock scheduling: Classification, literature review and research agenda	2010	41	✓	✓	✓	✓		✓	✓		
3	Increasing warehouse order picking performance by sequence optimization	2011	8	✓	✓						✓	
4	Performance Analysis of Particle Swarm Optimization Algorithms for Jobs Scheduling in Data Warehouse	2012	17	✓	✓	✓	✓					
5	An integrated approach for warehouse analysis and optimization: A case study	2015	56	✓	✓							
6	Improving warehouse responsiveness by job priority management: A European distribution centre field study	2018	59	✓		✓						
7	Picker routing in the mixed-shelves warehouses of e-commerce retailers	2018	22	✓	✓						✓	
8	Synchronized Scheduling of Make To Order Plant and CrossDocking Warehouse	2019	45	✓	✓					✓		
9	Multi-warehouse package consolidation for split orders in online retailing	2019	38	✓	✓			✓				

Article No.	Article title	Publication year	No. of citations	Ware-house	Optmi-zation	Job scheduling	Deadline	Repack/ Unpack	Multi-objective	Cross docking	Picker routing	Logist-ics
10	Order Batching Optimization for Warehouses with Cluster-Picking	2019	24	√	√						√	
11	How to optimize storage classes in a unit-load warehouse	2019	31	√	√		√					√
12	Two-stage storage assignment to minimize travel time and congestion for warehouse order picking operations	2020	62	√	√				√			
13	Order batch picking optimization under different storage scenarios for e-commerce warehouses	2020	30	√	√							
14	Cross-Docking: A Proven LTL Technique to Help Suppliers Minimize Products' Unit Costs Delivered to the Final Customers	2020	72	√	√	√				√		
15	Optimization of Warehouse Operations with Genetic Algorithms	2020	39	√	√						√	
16	Integrating storage location and order picking problems in warehouse planning	2020	58	√	√						√	
17	IS project	-	-	√	√	√	√	√	√			

CHAPTER 3
METHODOLOGY

In this section, the method of the approach is presented in a flow chart form along with the description of each step.

3.1 Method of approach

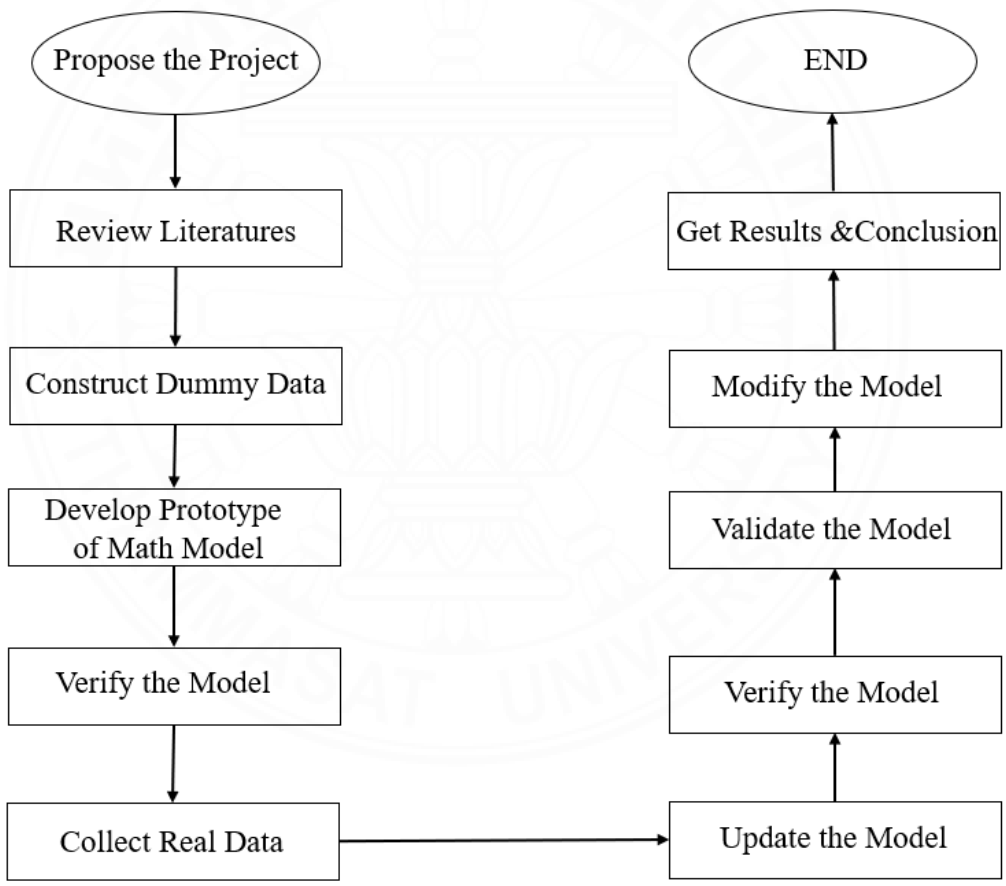

Figure 3.1 Method of approach

Step 1 is the literature review. This step is to study the related journal from the outsource about the warehouse operation and math model to optimize the cost, tardiness, order scheduling, and about repack operation. After the project is proven as it is significant and new, the step is moving forward to construct a dummy data set for the primary model that would be constructed. Then, the prototype of the model is created based on our assumption and the dummy data. There are in total of 3 models that are generated in this step: 1. The model to minimize operation cost according to repack operation, 2. The model to schedule the order to minimize tardiness cost, and 3. The multi-objective model to minimize both objectives. Next, after the multi-objective model is constructed and verified by setting an extreme condition to see if the logic is correct or not. Then, the real data from the warehouse of the painting company is collected and it is fit to our model. After the real data is fit into the model to optimize total cost and it is already verified and validated, the model will be modified by some conditions as user preference to get various scenarios that could happen. Finally, the conclusion of all scenarios would be made as an application for the user.

CHAPTER 4
RESULT

4.1 Prototype of math model

In the study, before the math model is getting big and applied to the real data, the prototype is constructed to simulate and explore the feasibility of the project first. Therefore, in this paper, there are three prototypes with three objective functions constructed: 1. Minimize Operational Cost, 2. Minimize Tardiness and Earliness Cost, and 3. Bi-Objective Function

4.1.1 Prototype I: Minimize operational cost

This model is a single-objective model that aims to minimize operational cost which is an unpacking and repacking cost of the wholesaler (seller) and the holding cost of the retailer (buyer). And the math model is set as following:

Index

i Order {1,2, 3, …}

Input Parameters

Q_i Quantity (Unit)

F Full case (Unit)

h Holding cost (%)

W Wage (Baht)

p Price per unit (Baht)

Decision Variables

RC_i Repacking cost (Baht)

HC_i Holding cost (Baht)

Y_i 1 if order i does repacking operation,

0 if order i does not have repacking operation

Mathematical Model

Objective Function Minimize $\sum_i (HC_i + RC_i)$

Subject to

$0.004 * MOD(Q_i, F) = Repack_i \quad \forall i \quad (4.1)$

$MOD(F - MOD(Q_i, F), F) * p * h * (1 - Y_i) = HC_i \quad \forall i \quad (4.2)$

$Repack_i * W * Y_i = RC_i \quad \forall i \quad (4.3)$

Y_i is Binary $\quad \forall i \quad (4.4)$

The objective is to minimize the total cost which is the holding cost and repacking cost. Equation (4.1) and (4.3) is for the repacking cost calculation and equation (4.2) is for holding cost calculation. If there is a repacking operation at the seller, there is no holding cost at the buyer occurs. Constraint (4.4) define the binary variable.

Then, this model is run using a solver in excel to see if the result is valid or not. Next, this model is implemented into the CPLEX optimizer program since the last model contains a 3-dimensional mathematical model which is the limitation of the excel. After that, the result is generated which is equal to the result generated by an excel. This process is to verify that the model in CPLEX is correctly constructed.

4.1.2 Prototype II: Minimize tardiness cost

When the job is done late or early, there is a penalty which is a cost per unit of time that the company or the manufacturer has to pay, therefore, this single-objective model aims to minimize total tardy and early cost by scheduling the job into the most efficient sequence that meets the deadline. And the math model is set as following:

Indices

i Order {1,2, 3, …}

j Sequence {1,2, 3, …}

Input Parameters

P_i Total processing time of order i (Day)

D_i Deadline of order i (Day)

TC	Tardy cost (Baht)
EC	Early cost (Baht)

Decision Variables

X_{ij}	1 if order i is in sequence j
	0 if order i is not in sequence j
C_j	Completion time of sequence j (Day)
DD_j	Deadline of sequence j (Day)
T_j	Tardiness of sequence j (Day)
E_j	Earliness of sequence j (Day)

Mathematical Model

Objective Function $\quad$ Minimize $\sum_j (T_j*TC+E_i*EC)$

Subject to	$\sum_j X_{ij} = 1$	$\forall$ i	(4.5)
	$\sum_i X_{ij} = 1$	$\forall$ j	(4.6)
	$\sum_i (P_i*X_{ij}) = C_j$	j ∈ {1}	(4.7)
	$C_{j-1}+\sum_i (P_i*X_{ij}) = C_j$	j ∈ {2,3,...,n}	(4.8)
	$\sum_i (D_i*X_{ij}) = DD_j$	$\forall$ j	(4.9)
	$T_j-E_j = C_j-DD_j$	$\forall$ j	(4.10)
	$T_j, E_j, C_j, DD_j \geq 0$	$\forall$ j	(4.11)
	X_{ij} is Binary	$\forall$ i, $\forall$ j	(4.12)

The objective is to minimize total tardiness and earliness cost. Constraint (4.5) is indicating that order i must be in one of the sequence and constraint (4.6) is indicating that only one order is in each of the sequence. Equations (4.7) and (4.8) are to calculate the completion time of the sequences. While equation (4.9) is to calculate the due date of the sequence from the order. Equation (4.10) is for calculating tardiness and earliness of order in sequence j. Constraints (4.11) and (4.12) are the non-negativity and binary conditions.

4.1.3 Prototype III: Bi-objective model

After the models of prototype, I and II have been constructed and validated successfully, then the prototype III is created accordingly. This model aims to optimize on both objectives of prototype model I and II which are operational cost and tardiness cost by a min-max approach. This approach is to find the solution that minimizes the max deviation of the two objectives from their optimal results. In conclusion, this model gives the solution that considers a job scheduling with the unpack/repack operations to optimize the total supply chain cost. And the math model is set as following:

<u>Indices</u>

i	Order {1,2, 3, …}
j	Sequence {1,2, 3, …}
k	Repack {0,1}

<u>Input Parameters</u>

$ProTime_i$	Total processing time of order i (Day)
D_i	Deadline of order i (Day)
$Start_i$	Start date of order i (Day)
TC	Tardy cost (Baht)
EC	Early cost (Baht)
Q_i	Quantity (Unit)
F	Full case (Unit)
h	Holding cost (%)
W	Wage (Baht)
p	Price per unit (Baht)
$MinTar$	Minimum tardiness cost (Baht)
$MaxTar$	Maximum tardiness cost (Baht)
$MinTC$	Minimum total cost (Baht)
$MaxTC$	Maximum total cost (Baht)

Decision Variables

X_{ijk}	1 if order i is in sequence j
	0 if order i is not in sequence j
C_j	Completion time of sequence j (Day)
DD_j	Deadline of sequence j (Day)
T_j	Tardiness of sequence j (Day)
E_j	Earliness of sequence j (Day)
RC_i	Repacking cost of order i (Baht)
HC_i	Holding cost of order i (Baht)
TotalCost	Total operational cost (Baht)
TarCost	Total tardiness cost (Baht)
SigCost	Sigma of operational cost or deviation from optimal operational cost
SigTar	Sigma of tardiness cost or deviation from optimal tardiness cost
Z	Maximum deviation from optimal solution

Mathematical Model

Objective Function *Minimize* Z

Subject to $0.004*MOD(Q_i, F)*W*\sum_j X_{ij1} = RC_i$ $\forall$ i (4.13)

$MOD(F-MOD(Q_i, F),F)*p*(h/4)*(1-\sum_j X_{ij1}) = HC_i$ $\forall$ i (4.14)

$\sum_k \sum_j X_{ijk} = 1$ $\forall$ i (4.15)

$\sum_k \sum_i X_{ijk} = 1$ $\forall$ j (4.16)

$\sum_i X_{i11}*MOD(Q_i, F)*0.004 + \sum_k \sum_i X_{i1k}*ProTime_i = C_1,$ j $\in$ {1} (4.17)

$C_1 + \sum_i X_{ij1}*MOD(Q_i, F)*0.004 + \sum_k \sum_i X_{ijk}*ProTime_i = C_{j+1}$ j $\in$ {2,3,...,n} (4.18)

$\sum_k \sum_i (X_{ijk}*D_i) = DD_j$ $\forall$ j (4.19)

$T_j-E_j = C_j-DD_j$ $\forall$ j (4.20)

$C_j >= Start_j$ $\forall$ j (4.21)

$\sum_i ((HC_i) + (RC_i)) = TotalCost$ (4.22)

$\sum_j TC*T_j = TarCost$ (4.23)

(TotalCost - MinTC) / (MaxTC-MinTC) = SigCost (4.24)

(TarCost-MinTar) / (MaxTar-MinTar) = Sigtar (4.25)

$Z \geq Sigcost$ (4.26)

$Z \geq Sigtar$ (4.27)

$T_j, E_j, C_j, DD_j \geq 0$ $\forall j$ (4.28)

X_{ijk} is Binary $\forall i, \forall j$ (4.29)

The objective function is to minimize the largest deviation from optimal solutions across the two functions considered. Equation (4.13) is for the repacking cost of each order calculation of the seller and equation (4.14) is for holding cost calculation of each order of the buyer. If there is a repacking operation at the seller, there is no holding cost at the buyer occurs. Constraint (4.16) is indicating that each order must be in one of the sequences while constraint (4.17) is indicating that only one order is in each of the sequence. Equations (4.17) and (4.18) are to calculate the completion time of the sequences. While equation (4.19) is to calculate the due date of the sequence from the order. Equation (4.20) is for calculating tardiness and earliness of order in each sequence. Constraint (4.21) is for regulating that the order must not be picked up before its start date. Equations (4.22) and (4.23) are to calculate the total operational cost and total tardiness cost. Constraints (4.24) and (4.25) define the deviation between each objective and its optimal solution by normalizing them into the range of 0-1. Constraints (4.26) and (4.27) are to formulate a min-max goal attainment on the deviations of the two objectives. Constraints (4.28) and (4.29) are the non-negativity and binary conditions.

4.2 Final math model

After all the three prototypes have completed, then the final model is constructed. The real data from the painting company in Thailand has been applied into the model. Basically, the final math model and the math model of prototype III are the same, but the only difference is that the final model concerns about the quantity of late order as well while the prototype does not. So that there are some modifications on the model which is making some of the decision variables (Tardiness (T), Earliness (E), and Completion time (C)) to be two dimensional variables which contain Order (i) and Sequence (j). In conclusion, the final math model is shown as following:

Indices

i	Order {1,2, 3, …}
j	Sequence {1,2, 3, …}
k	Repack {0,1}

Input Parameters

$ProTime_i$	Total processing time of order i (Day)
D_i	Deadline of order i (Day)
$Start_i$	Start date of order i (Day)
TC	Tardy cost (Baht)
EC	Early cost (Baht)
Q_i	Quantity (Unit)
F	Full case (Unit)
h	Holding cost (%)
W	Wage (Baht)
p	Price per unit (Baht)
M	Big number
$MinTar$	Minimum tardiness cost (Baht)
$MaxTar$	Maximum tardiness cost (Baht)
$MinTC$	Minimum total cost (Baht)
$MaxTC$	Maximum total cost (Baht)

Decision Variables

X_{ijk}	1 if order i is in sequence j
	0 if order i is not in sequence j
C_{ij}	Completion time of sequence j (Day)
T_{ij}	Tardiness of order i in sequence j (Day)
E_{ij}	Earliness of order i in sequence j (Day)
RC_i	Repacking cost of order i (Baht)
HC_i	Holding cost of order i (Baht)
Tar_i	Tardiness cost of order i (Baht)

TotalCost	Total operational cost (Baht)
TarCost	Total tardiness cost (Baht)
SigCost	Sigma of operational cost or deviation from optimal operational cost
SigTar	Sigma of tardiness cost or deviation from optimal tardiness cost
Z	Maximum deviation from optimal solution

Mathematical Model

Objective Function *Minimize* Z

Subject to

$$0.004*MOD(Q_i, F)*W*\sum_j X_{ij1} = RC_i \quad \forall\, i \quad (4.30)$$

$$MOD(F-MOD(Q_i, F),F)*p*(h/4)*(1-\sum_j X_{ij1}) = HC_i \quad \forall\, i \quad (4.31)$$

$$\sum_j \sum_k X_{ijk} = 1 \quad \forall\, i \quad (4.32)$$

$$\sum_i \sum_k X_{ijk} = 1 \quad \forall\, j \quad (4.33)$$

$$\sum_i X_{i11}*MOD(Q_i, F)*0.004 + \sum_i \sum_k X_{i1k}*ProTime_i = \sum_i C_{i1}, \quad j \in \{1\} \quad (4.34)$$

$$C_1 + \sum_i X_{ij1}*MOD(Q_i, F)*0.004 + \sum_k \sum_i X_{ijk}*ProTime_i = \sum_i C_{i,j+1} \quad j \in \{2,3,...,n\} \quad (4.35)$$

$$\sum_i \sum_j \sum_k X_{ijk}*M \geq C_{ij} \quad (4.35.1)$$

$$\sum_j (T_{ij}-E_{ij}) = \sum_j (C_{ij}-D_i) \quad \forall\, i \quad (4.36)$$

$$\sum_k X_{ijk}*M \geq T_{ij} \quad \forall\, i\, \forall\, j \quad (4.36.1)$$

$$\sum_k X_{ijk}*M \geq E_{ij} \quad \forall\, i\, \forall\, j \quad (4.36.2)$$

$$\sum_i C_{ij} >= Start_j \quad \forall\, j \quad (4.37)$$

$$\sum_i ((HC_i) + (RC_i)) = TotalCost \quad (4.38)$$

$$\sum_j \sum_k (p*0.35/30* T_{ij}*Q_i+EC*E_{ij}) = Tar_i \quad \forall\, i \quad (4.39)$$

$$\sum_i Tar_i = TarCost \quad (4.40)$$

$$(TotalCost - MinTC) / (MaxTC-MinTC) = Sigcost \quad (4.41)$$

$$(TarCost-MinTar) / (MaxTar-MinTar) = Sigtar \quad (4.42)$$

$$Z \geq Sigcost \quad (4.43)$$

$$Z \geq Sigtar \quad (4.44)$$

$$T_{ij},E_{ij},C_{ji} \geq 0 \quad \forall\, i \forall\, j \quad (4.45)$$

$$X_{ijk} \text{ is Binary} \quad \forall\, i,\forall\, j \quad (4.46)$$

For the final model, mostly are similar to the prototype model III. The difference is that this model considers the quantity inside of each late order. The objective function is to minimize the largest deviation from optimal solutions across the two functions considered. Equation (4.30) is for the repacking cost of each order calculation of the seller and equation (4.31) is for holding cost calculation of each order of the buyer. If there is a repacking operation at the seller, there is no holding cost at the buyer occurs. Constraint (4.33) is indicating that order must be in one of the sequences while constraint (4.34) is indicating that only one order is in each of the sequence. Equations (4.34) and (4.35) are to calculate the completion time of the sequences. Constraint (4.35.1) is to make the completion time of the sequence that is not selected be zero. Equation (4.36) is for calculating tardiness and earliness of order in each sequence. Constraint (4.36.1) and (4.37.2) are to make the tardiness and earliness of the non-selected order and sequence to be zero. Constraint (4.37) is for regulating that the order must not be picked up before its start date. Equation (4.38) is for calculating the total operational cost. Equations (4.39) and (4.40) are to calculate total tardiness cost and the profit margin is 35% while the order will be cancelled within the lateness of 30 days. Constraints (4.41) and (4.42) define the deviation between each objective and its optimal solution by normalizing them into the range of 0-1. Constraints (4.43) and (4.44) are to formulate a min-max goal attainment on the deviations of the two objectives. Constraints (4.45) and (4.46) are the non-negativity and binary conditions.

4.2.1 Output of math model

There are many values that are collected including: Wcost which is the weight of the operational cost, Wtar which is the weight of tardiness cost, Operational cost which is the cost consisting of Repacking cost and Holding cost of buyer, Tardiness cost which is the cost of lost opportunity of the late orders, Total supply chain cost which is the sum of operational cost and the tardiness cost, Cost saving which is the saving of the particular scenario comparing to the most expensive one, Operation and Tardiness satisfaction are the satisfaction percentage (compared to the lowest value of operational and tardiness cost among all scenarios), Average satisfaction is the average of operation and tardiness satisfaction, Factory warehouse (Seller) is the cost that the seller has to pay for unpacking and repacking operation and the cost of lost opportunity if the order is delivered late to the customers, and lastly, Retail or Buyer holding cost which is the cost that the buyer has to pay for holding the excess unit apart from their customer's demand. While on each column, there are various weights that are generated since the nature of the data is unknown and different scenarios can also be seen when the importance of operational cost and tardy cost are not at the same level. The costs can be seen separately between wholesaler (Repack/Unpack cost and Tardy cost) and retailer cost (Holding cost).

4.3 Results

In this section, the results from the model will be shown and discussed. There are in total of 4 sets of data that are run by the math model. Each data set contains the detail of orders within 7-day period, so that the detail in each of the data set will be varied by the number of order and the quantity within those placed orders.

4.3.1 Result of data set 1

Table 4.1 Result of data set 1

Wcost	1	0.9	0.8	0.7	0.6
Wtar	0	0.1	0.2	0.3	0.4
Operation cost	788	827	813	1,041	1,535
Tardiness cost	708,780	372,200	313,400	380,780	393,850
Total cost	709,568	373,027	314,213	381,821	395,385
Cost saving	0	336,541	395,355	327,747	314,182
Operation satisfaction	100.00%	99.60%	99.75%	97.38%	92.26%
Tardiness satisfaction	0.00%	84.98%	99.82%	82.81%	79.51%
Average satisfaction	50.00%	92.29%	99.78%	90.10%	85.88%
Factory Warehouse (Seller)	708,960	372,374	313,568	380,950	394,020
- Repack/Unpack cost	180	174	168	170	170
- Tardy cost	708,780	372,200	313,400	380,780	393,850
Retailer (Buyer) (Holding cost)	608	653	645	870	1,365

Table 4.2 Result of data set 1 (Cont.)

Wcost	0.5	0.4	0.3	0.2	0.1	0
Wtar	0.5	0.6	0.7	0.8	0.9	1
Operation cost	1,437	789	2,071	1,094	805	10,438
Tardiness cost	360,530	412,340	378,130	448,340	391,280	312,690
Total cost	361,967	413,129	380,201	449,434	392,085	323,128
Cost saving	347,601	296,439	329,367	260,134	317,483	386,439
Operation satisfaction	93.28%	99.99%	86.71%	96.83%	99.82%	0.00%
Tardiness satisfaction	87.92%	74.84%	83.48%	65.75%	80.16%	100.00%
Average satisfaction	90.60%	87.42%	85.09%	81.29%	89.99%	50.00%
Factory Warehouse (Seller)	360,699	412,514	378,281	448,511	391,447	312,770
- Repack/Unpack cost	169	174	151	171	167	80
- Tardy cost	360,530	412,340	378,130	448,340	391,280	312,690
Retailer (Buyer) (Holding cost)	1,268	615	1,920	923	638	10,358

Table 4.1 and 4.2 above show the result of data set 1. The left most of the table is where the weight of tardiness is 0, which means the lateness of the order is not concerned at all. But, in reality, it is impossible that the lateness of the order is not included in the process both for the seller or buyer. Thus, this is an extreme case that would not happen even though the operational cost is the lowest.

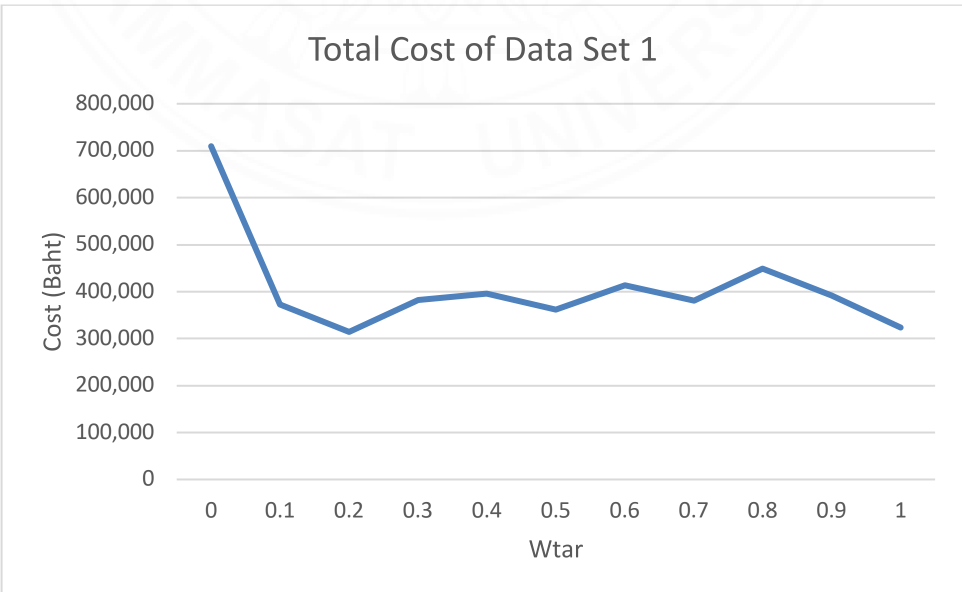

Figure 4.1 Total cost of data set 1

The best scenario of the lowest total cost of the supply chain is taken placed at weight of operational cost of 0.8 and weight of tardiness of 0.2 with the value of 314,213 baht. Also, the graph in Figure 4.1 above indicates that after the optimal point, the total cost is increased when the weight of tardiness is higher. And the worst scenario occurs on the left most of the graph when the tardiness of the orders is not considered at all with a value of 709,568 baht.

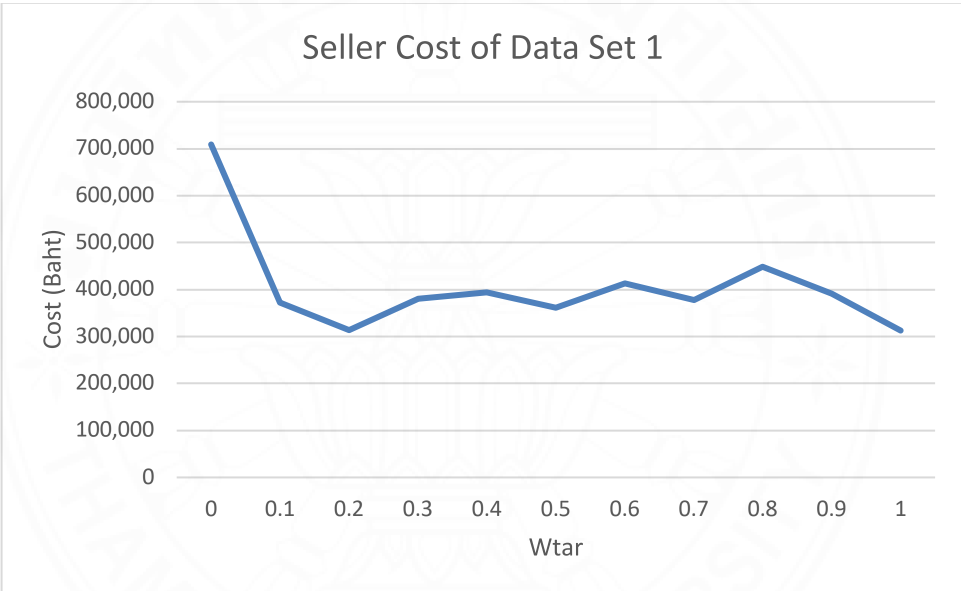

Figure 4.2 Seller cost of data set 1

The lowest total cost of the seller occurs at weight of operational cost of 0.8 and weight of tardiness of 0.2 with the total cost of 313,568 baht and the unpack/repack cost of 168 baht which is the second best among all the scenarios while the tardy cost is 313,400 baht. Also, the graph in Figure 4.2 above indicates that after the pessimistic case at the weight of tardiness equals to 0, the cost is dramatically decreased.

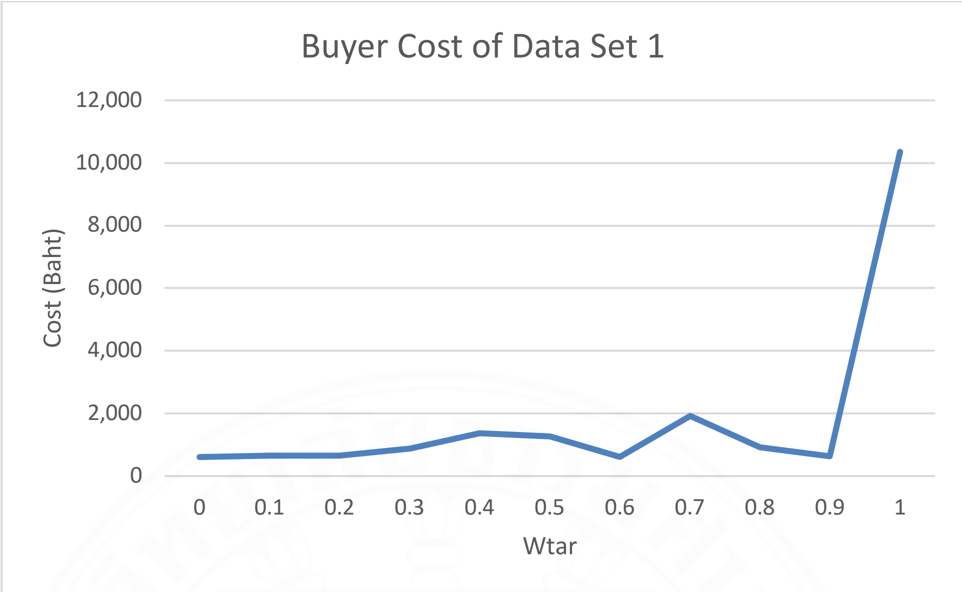

Figure 4.3 Buyer cost of data set 1

The optimistic case of the buyer occurs at weight of operational cost of 0.4 and weight of tardiness of 0.6 with the total holding cost of 615 baht. The graph in Figure 4.3 above shows that the cost at weight of operational cost of 1 and weight of tardiness of 0 gives an extremely high value of 10,358 because the seller only focuses on delivery as fast as possible, so they will not allow unpack or repack operations. Therefore, the buyer must hold for the excess units from their customer's demand.

4.3.2 Result of data set 2

Table 4.3 Result of data set 2

Wcost	1	0.9	0.8	0.7	0.6
Wtar	0	0.1	0.2	0.3	0.4
Operation cost	229	313	570	570	570
Tardiness cost	982,160	761,420	844,550	774,290	789,780
Total cost	982,389	761,733	845,120	774,860	790,350
Cost saving	0.00	220,656	137,269	207,529	192,039
Operation satisfaction	100.00%	99.19%	96.71%	96.71%	96.71%
Tardiness satisfaction	0.00%	74.39%	46.37%	70.05%	64.83%
Average satisfaction	50.00%	86.79%	71.54%	83.38%	80.77%
Factory Warehouse (Seller)	982,389	761,643	844,775	774,515	790,005
- Repack/Unpack cost	229.47	223.34	225.02	225.02	225.02
- Tardy cost	982,160	761,420	844,550	774,290	789,780
Retailer (Buyer) (Holding cost)	0	90	345	345	345

Table 4.4 Result of data set 2 (Cont.)

Wcost	0.5	0.4	0.3	0.2	0.1	0
Wtar	0.5	0.6	0.7	0.8	0.9	1
Operation cost	570	570	570	238	570	10,589
Tardiness cost	694,230	798,180	845,100	775,520	685,410	685,410
Total cost	694,800	798,750	845,670	775,758	685,980	695,999
Cost saving	287,589	183,639	136,719	206,632	296,409	286,390
Operation satisfaction	96.71%	96.71%	96.71%	99.92%	96.71%	0.00%
Tardiness satisfaction	97.03%	62.00%	46.19%	69.63%	100.00%	100.00%
Average satisfaction	96.87%	79.36%	71.45%	84.78%	98.36%	50.00%
Factory Warehouse (Seller)	694,455	798,405	845,325	775,743	685,635	685,574
- Repack/Unpack cost	225	225	225	223	225	164
- Tardy cost	694,230	798,180	845,100	775,520	685,410	685,410
Retailer (Buyer) (Holding cost)	345	345	345	15	345	10,425

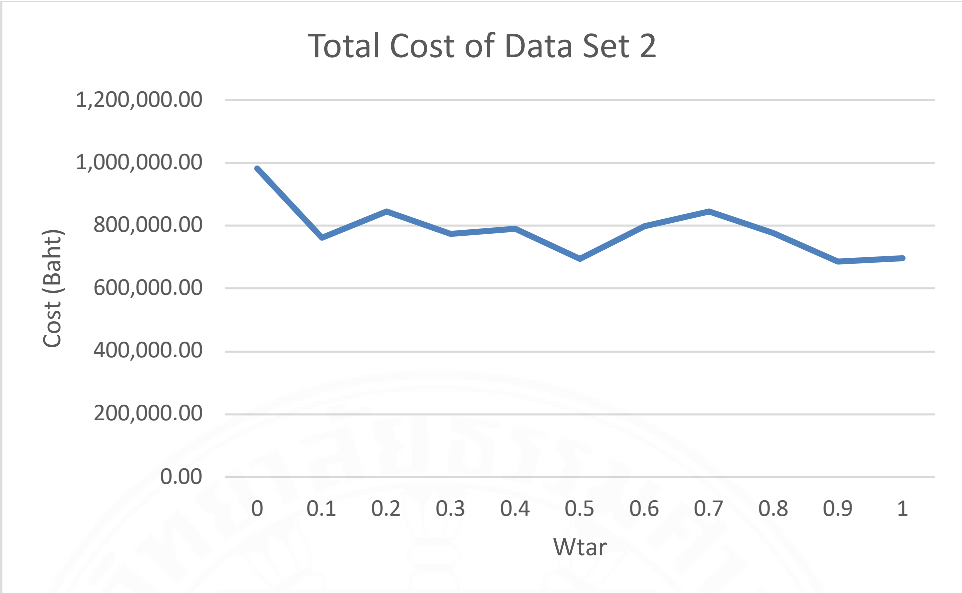

Figure 4.4 Total cost of data set 2

Figure 4.4, Table 4.3 and 4.4 above show the result of data set 2. The best scenario of the lowest total cost of the supply chain is taken placed at weight of operational cost of 0.1 and weight of tardiness of 0.9 with the value of 685,980 baht. And the worst scenario occurs on the left most of the graph when the tardiness of the orders is not considered at all with a value of 982,389.47 baht.

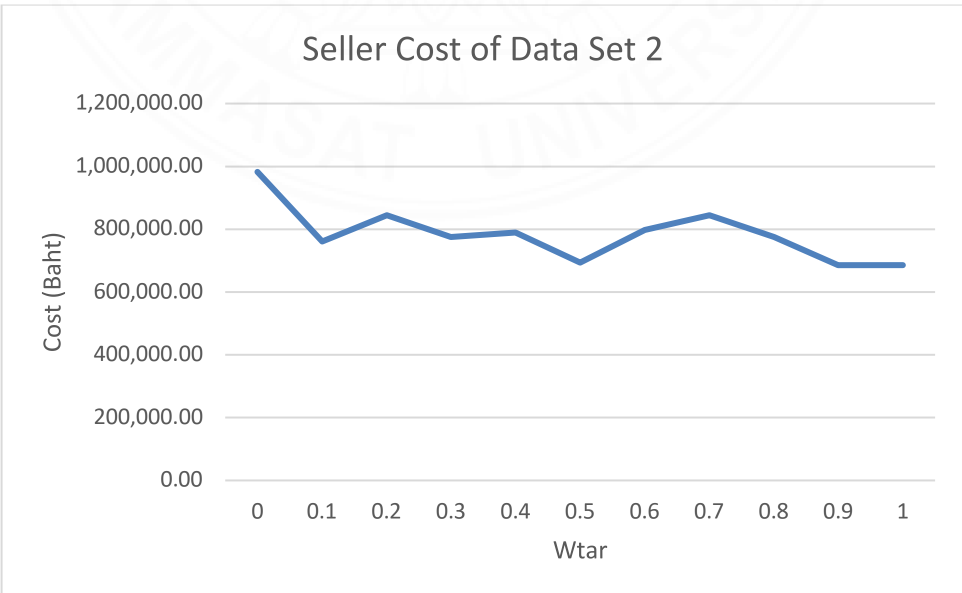

Figure 4.5 Seller cost of data set 2

The lowest total cost of the seller occurs at weight of operational cost of 0 and weight of tardiness of 1 with the total cost of 685,573 baht and the unpack/repack cost of 164 baht which is the lowest one among all the scenarios while the tardy cost is 685,410 baht. The graph in Figure 4.5 above indicates that after the pessimistic case at weight of tardiness equals to 0, the cost is gradually decreased when the weight of tardiness is increasing, and the weight of operational cost is decreasing even though the values are varied at some points.

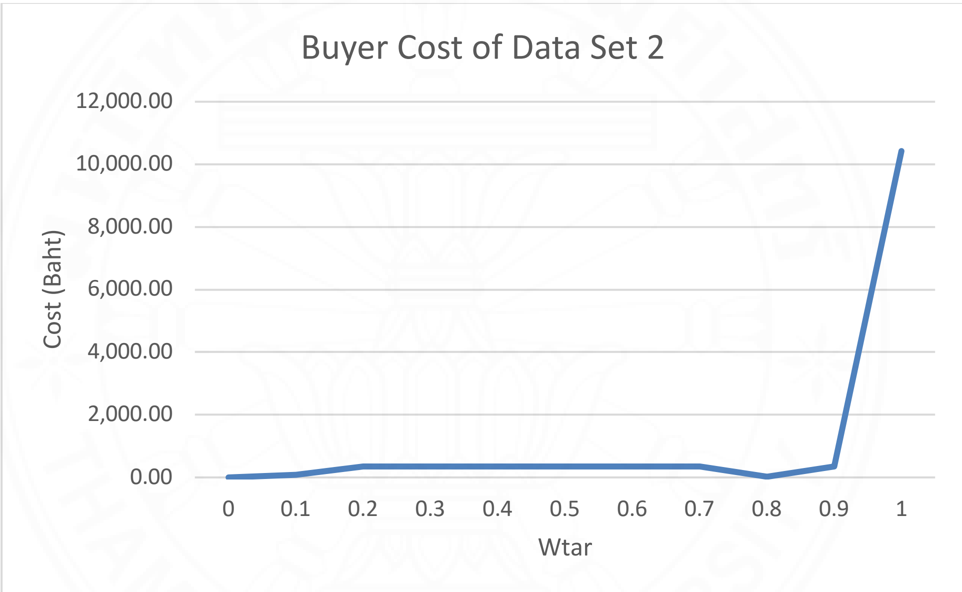

Figure 4.6 Buyer cost of data set 2

For the cost of buyer of data set 2, even though the holding cost is 0 when the weight of tardiness is 0, this case is not likely to happened in the real world. Therefore, the optimal value of the holding cost occurs at weight of tardiness is 0.8 with a holding cost of 15 baht while the worst case occurs at the weight of tardiness of 1 with the value of 10,425 baht. Also, Figure 4.6 above proves that the cost is dramatically increased when the weight of tardiness reaches 1.0.

4.3.3 Result of data set 3

Table 4.5 Result of data set 3

Wcost	1	0.9	0.8	0.7	0.6
Wtar	0	0.1	0.2	0.3	0.4
Operation cost	176	176	176	176	176
Tardiness cost	268,280	258,110	255,280	260,080	258,750
Total cost	268,456	258,286	255,456	260,256	258,926
Cost saving	0	10,170	13,000	8,200	9,530
Operation satisfaction	100.00%	100.00%	100.00%	100.00%	100.00%
Tardiness satisfaction	0.00%	39.77%	50.84%	32.07%	37.27%
Average satisfaction	50.00%	69.89%	75.42%	66.03%	68.64%
Factory Warehouse (Seller)	268,456	258,286	255,456	260,256	258,926
- Repack/Unpack cost	176	176	176	176	176
- Tardy cost	268,280	258,110	255,280	260,080	258,750
Retailer (Buyer) (Holding cost)	0	0	0	0	0

Table 4.6 Result of data set 3 (Cont.)

Wcost	0.5	0.4	0.3	0.2	0.1	0
Wtar	0.5	0.6	0.7	0.8	0.9	1
Operation cost	176	176	176	176	176	4,637
Tardiness cost	253,280	248,320	258,320	249,370	248,230	242,710
Total cost	253,456	248,496	258,496	249,546	248,406	247,347
Cost saving	15,000	19,960	9,960	18,910	20,050	21,109
Operation satisfaction	100.00%	100.00%	100.00%	100.00%	100.00%	0.00%
Tardiness satisfaction	58.66%	78.06%	38.95%	73.95%	78.41%	100.00%
Average satisfaction	79.33%	89.03%	69.48%	86.98%	89.21%	50.00%
Factory Warehouse (Seller)	253,456	248,496	258,496	249,546	248,406	242,862
- Repack/Unpack cost	176	176	176	176	176	152
- Tardy cost	268,280	248,320	258,320	268,280	268,280	242,710
Retailer (Buyer) (Holding cost)	0	0	0	0	0	4,485

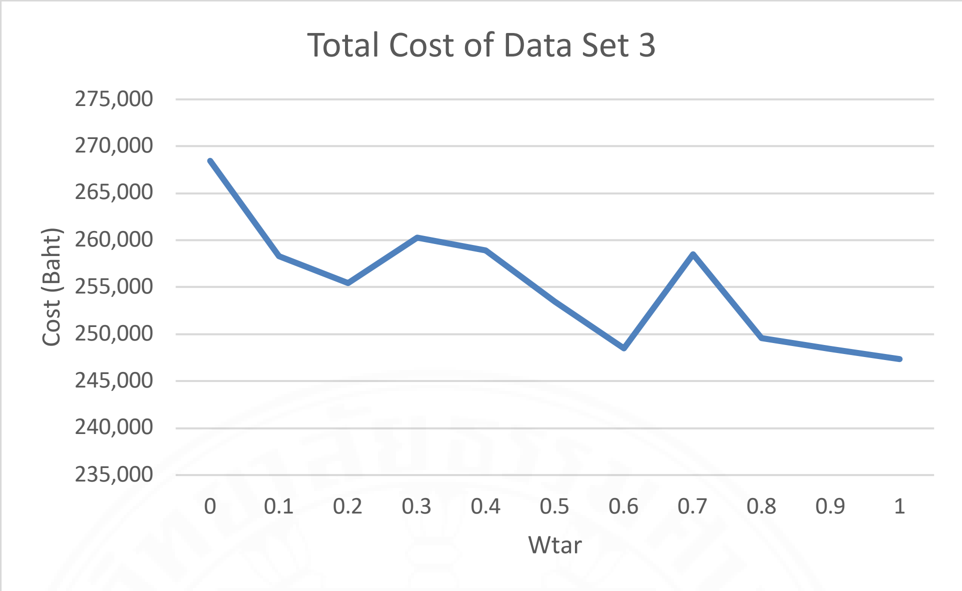

Figure 4.7 Total cost of data set 3

Table 4.5 and 4.6 above shows the result of data set 3. The lowest total cost takes place at weight of operational cost of 0 and weight of tardiness of 1 with the total cost of 247,347 baht. The pessimistic case occurs at weight of tardiness equals to 0 with the cost of 268,456 baht. Also, the trend in the graph in Figure 4.7 above indicates that the cost is decreased when they focus more on tardiness.

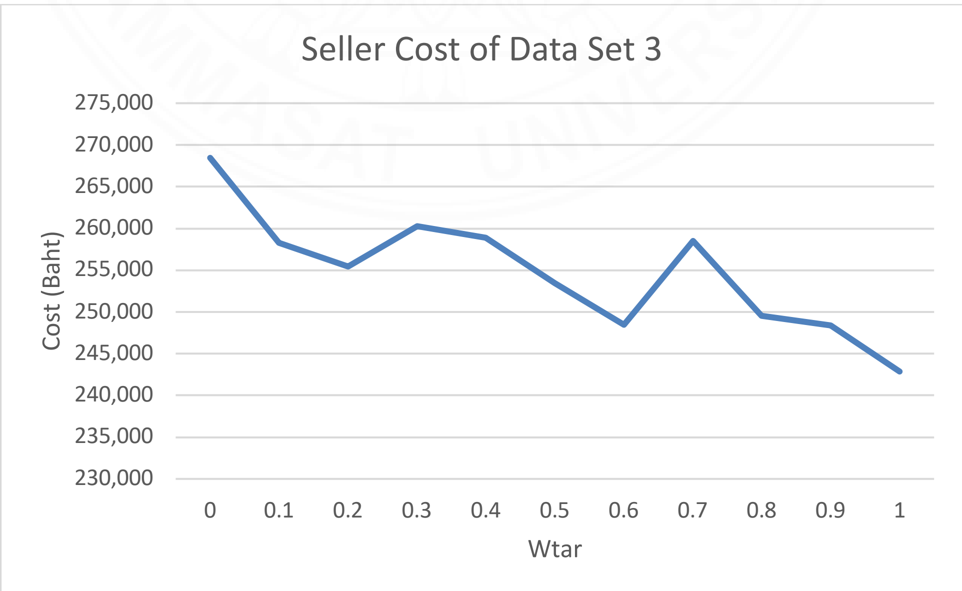

Figure 4.8 Seller cost of data set 3

The lowest total cost of the seller occurs at weight of operational cost of 0 and weight of tardiness of 1 with the total cost of 242,862 baht and the unpack/repack cost of 152 baht which is the lowest one among all the scenarios while the tardy cost is 242,710 baht. And the highest total seller cost happens at the left most in which the weight of operational cost is 1 and tardiness is 0. The graph in Figure 4.8 above shows that the trend of the seller cost is decreasing when the weight of tardiness is increasing.

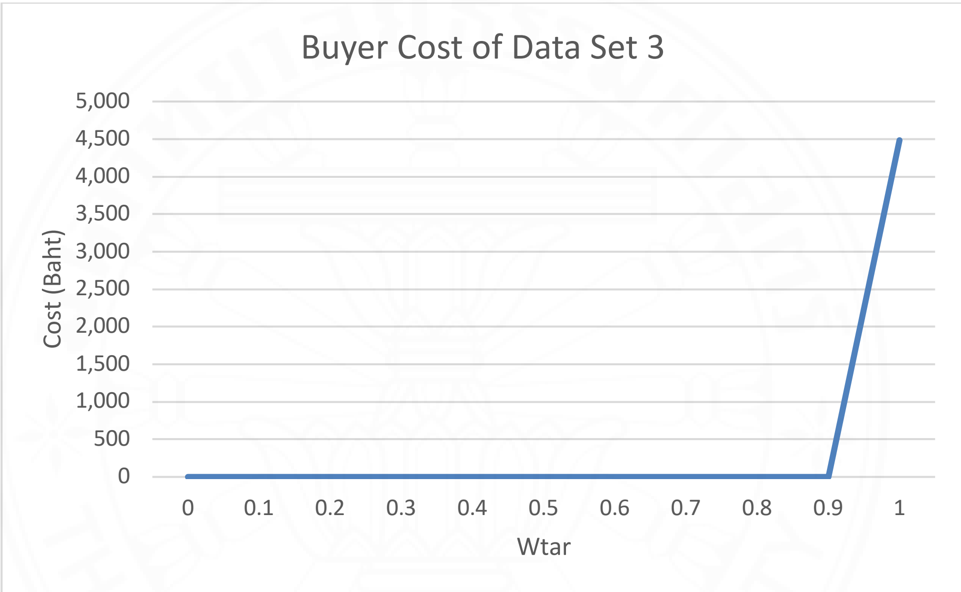

Figure 4.9 Buyer cost of data set 3

For the buyer cost of data set 3, the holding cost is 0 when the weight of tardiness is 0 until the weight reaches 0.9. Therefore, the optimal value of the holding cost occurs in a range of weight of tardiness is 0 till 0.9 with a holding cost of 0 baht as shown in the Figure 4.9 while the worst case occurs at the weight of tardiness of 1 with the value of 4,485 baht.

4.3.4 Result of data set 4

Table 4.7 Result of data set 4

Wcost	1	0.9	0.8	0.7	0.6
Wtar	0	0.1	0.2	0.3	0.4
Operation cost	234	234	234	234	234
Tardiness cost	1,427,600	1,170,900	1,174,000	1,018,900	1,207,400
Total cost	1,427,834	1,171,134	1,174,234	1,019,134	1,207,634
Cost saving	0	256,700	253,600	408,700	220,200
Operation satisfaction	100.00%	100.00%	100.00%	100.00%	100.00%
Tardiness satisfaction	0.00%	36.56%	36.12%	58.22%	31.37%
Average satisfaction	50.00%	68.28%	68.06%	79.11%	65.68%
Factory Warehouse (Seller)	1,427,834	1,171,134	1,174,234	1,019,134	1,207,634
- Repack/Unpack cost	234	234	234	234	234
- Tardy cost	1,427,600	1,170,900	1,174,000	1,018,900	1,207,400
Retailer (Buyer) (Holding cost)	0	0	0	0	0

Table 4.8 Result of data set 4 (Cont.)

Wcost	0.5	0.4	0.3	0.2	0.1	0
Wtar	0.5	0.6	0.7	0.8	0.9	1
Operation cost	234	234	234	234	234	13,338
Tardiness cost	1,025,400	894,180	747,960	960,230	1,155,300	725,550
Total cost	1,025,634	894,414	748,194	960,464	1,155,534	738,888
Cost saving	402,200	533,420	679,640	467,370	272,300	688,946
Operation satisfaction	100.00%	100.00%	100.00%	100.00%	100.00%	0.00%
Tardiness satisfaction	57.29%	75.98%	96.81%	66.57%	38.79%	100.00%
Average satisfaction	78.64%	87.99%	98.40%	83.29%	69.39%	50.00%
Factory Warehouse (Seller)	1,025,634	894,414	748,194	960,464	1,155,534	725,703
- Repack/Unpack cost	234	234	234	234	234	153
- Tardy cost	1,025,400	894,180	747,960	960,230	1,155,300	725,550
Retailer (Buyer) (Holding cost)	0	0	0	0	0	13,185

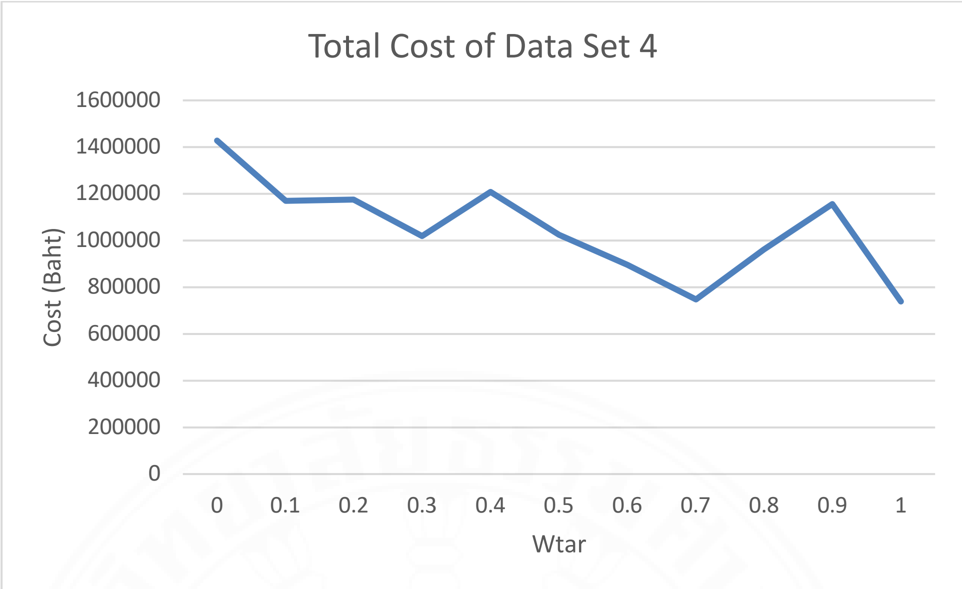

Figure 4.10 Total cost of data set 4

Table 4.7 and 4.8 above show the result of data set 4. The optimistic case with the best total cost takes place at weight of operational cost of 0 and weight of tardiness of 1 with the total cost of 738,888 baht. The pessimistic case occurs at weight of tardiness equals to 0 with the cost of 1,427,834 baht. The trend in the graph in Figure 4.10 above indicates that the cost is decreased when the weight of tardiness is increasing, in other words, when they focus more on tardiness.

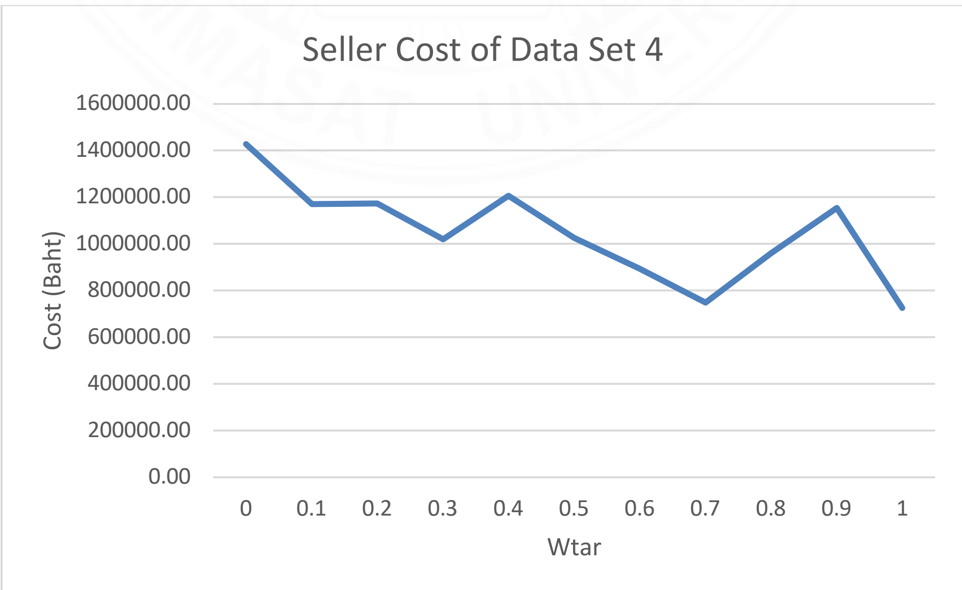

Figure 4.11 Seller cost of data set 4

The lowest total cost of the seller occurs at weight of operational cost of 0 and weight of tardiness of 1 with the total cost of 725,702 baht and the unpack/repack cost of 153 baht which is the lowest cost among all the scenarios while the tardy cost is 725,550 baht. The highest total seller cost happens when the weight of operational cost is 1 and tardiness is 0 with the value of 1,427,834. The graph in Figure 4.11 above shows that the trend of the seller cost is decreasing when the weight of tardiness is increasing.

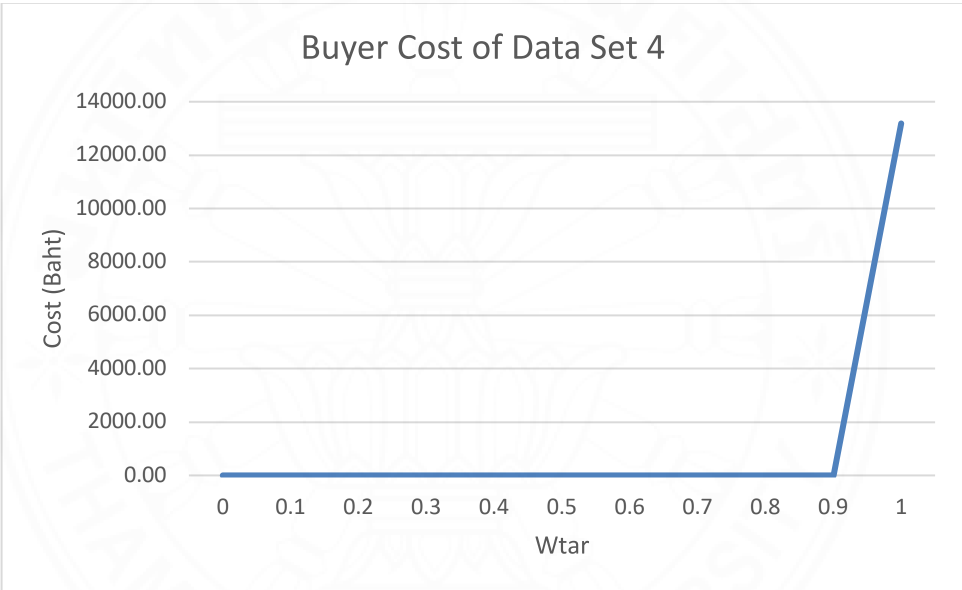

Figure 4.12 Buyer cost of data set 4

For the buyer cost of data set 4, the optimal value of the holding cost occurs in a range of weight of tardiness is 0 till 0.9 with a holding cost of 0 baht while the worst case occurs at the weight of tardiness of 1 with the value of 13,185 baht as illustrated in Figure 4.12 above.

4.4 Discussion

According to the results, there are three scenarios that can be concluded; 1. wholesalers (Seller) have more bargaining power, 2. Retailers (Buyer) have more bargaining power, and 3. There is coordination between seller and buyer.

Table 4.9 Scenario summary

Scenarios	Data Set 1 (Wcost,Wtardiness)	Data Set 2 (Wcost,Wtardiness)	Data Set 3 (Wcost,Wtardiness)	Data Set 4 (Wcost,Wtardiness)
Seller Advantage	(0,1)	(0,1)	(0,1)	(0,1)
Buyer Advantage	(0.6,0.4)	(0.2,0.8)	(1,0) - (0.1,0.9)	(1,0) - (0.1,0.9)
Coordination	(0.8,0.2)	(0.1,0.9)	(0,1)	(0,1)

Table 4.9 above indicates the scenario in term of (Wcost,Wtardiness) for each scenario of each data set. In scenario 1 which sellers have more bargaining power, they will prefer the case that their cost is the lowest which is the right-most case (W(cost) = 0 and W(tardiness) = 1). According to the results, they just want to deliver as fast as possible without any unpack and repack operations. That also means they deliver full cases as much as possible so that the buyer has to hold for those excess units from their demand. In addition, this scenario can also be called a responsive supply chain since it is focusing mainly on the on time delivery. In this case, both costs (tardiness and the repacking costs) of the seller are the cheapest one.

In scenario 2 in which buyers have more bargaining power, they will choose the case that gives them the lowest holding cost which are in the range of (W(cost),W(tardiness)) = from (0.9,0.1) to (0.1,0.9) since the best value occurs on this range depending on the data.

In the last scenario, if both echelons are coordinated and the cost that is being considered is the total cost of the supply chain, the lowest cost is most likely when W(cost) is 0.1, 0 and W(tardiness) = 0.1,1. These cases give the lowest total cost and also it is the one that retailers (buyers) prefer since their cost is the lowest one. Even though the best case of coordination of data set 1 fall into (0.8,0.2), the total cost is not much different from the value of scenario (0,1). Therefore, in order to make this case happen, there might be a compromise between buyer and seller. In summary, the retailer might share some benefits at least equal to the amount that the seller has to pay more than their lowest cost. Moreover, since this case gives the lowest supply chain cost, it is an efficient supply chain as well.

According to the three scenarios that have been discussed previously, the best scenario that gives the lowest total cost of the supply chain is where the coordination takes place. But, in reality, it depends on the situation that who has more bargaining power among seller and buyer. Therefore, the result of this model represents the scenarios that are likely to happen.

CHAPTER 5
CONCLUSION

There are four models that have been developed throughout this study: prototype I which aims for optimizing operational cost, prototype II which optimizes total tardiness and earliness cost, model III and final model which optimizes both objectives. In the final model, the weights of the two objectives are varied from scale 0 to 1 with a step of 0.1. And from the result, there are three situations with their best scenarios in the discussion. If there is a coordination among the supply chain, the cost would be lowest. While if the two echelons do not have coordination, the cost can be varied based on their bargaining power as discussed in the results. Therefore, to get the optimal cost, having coordination in the supply chain is recommended.

In this study, there are some limitations as well. Firstly, there is no uncertainty, and the data is discrete. Secondly, the penalty cost is assumed based on the real data of the company. Thirdly, there is only one SKU within the product in the warehouse. Lastly, the runtime of the model is limited for 2 minutes, thus the result might be a local optimal solution. But as all the scenarios are limited with the same runtime, the trend of the result could still be discussed.

In conclusion, the advantage of having a bi-objective optimization like this is to see the various scenarios that could happen and the result can be used as a tool for bargaining or finding a way for compromise to get the lowest supply chain cost.

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