OPTIMIZING INVENTORY CLASSIFICATION AND CONTROL

BY

RATHANAKSAMBATH LY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS ENGINEERING)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

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Abstract

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ABC inventory classification is a well-known approach to assign inventory items into three classes A, B, and C based on their sales and usage volume with 95%, 75% and 50% of service level respectively. It has been used for decades by many inventory managers to control inventory more efficiently. Behind its advantage, it usually shows some problems with an inventory budget and warehouse space because the ABC assignment of SKUs is made without an inventory budget and without considering available space. In this thesis, the optimal service level of ABC group model and the optimal classification model under restricted of inventory budget and warehouse space to maximize the profit is presented. We establish these proposed models to enhance the existing ABC approach to be more flexible in situation of limited inventory budget and warehouse space. These models are compared to identify the best inventory classification model and provide the decision aid for inventory managers.

Keywords: ABC inventory classification, Inventory Management.

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Chapter 1

Introduction

1.1. Introduction

Warehouses with thousands of different types of products are most likely to be quite ineffective at managing SKUs. To make a warehouse management more efficient, a planning and control approach needs to be utilized. An effective inventory planning and control system maintains a balance between two dimensions. First, it must guarantee maximizing customer service levels which protects a company against the critical backlog of any SKU. On the other hand, inventory cost must be minimized within provided budget. Nowadays, land renting fees are increasing; as a result, warehouse space should be minimized. The shared warehouse spaces for these products must be considered to prevent the required space of SKUs from exceeding the available warehouse space. Aggregation of a large number of SKUs into different groups, and identifying a common inventory control approach for each group is so popular (Chakravarty, 1981). ABC classification, which is broadly used in warehouse planning and method control, is designed to separate SKUs in three classes: A, B, and C as respectively very important to least important. It was first developed by GE in the 1950s (Flores and Clay Whybark, 1986; Guvenir and Erel, 1998). It is often found that a small proportion of the SKUs lead to the majority of a company's sales and revenue. The highest 20% of items are given the A class while 30% and 50% are classed as group B and group C, respectively (Flores and Clay Whybark, 1986).

Traditionally, the ABC inventory classification is considered to depend on a single criteria, which generally is the annual usage value given by the product of the annual demand and the average unit cost. The inventory manager can assign separated inventory policy on an individual group. They might take great care on group A because the assigned SKUs have a bigger profit share in company. They also can choose a suitable inventory policy for slow moving products, which are assigned to group C.

Single criteria could not generally illustrate the overall criticality of an item. The Multi-Criteria Inventory Classification (MCIC) approach, which includes many other criteria, such as lead time, unit cost, critical factor, and availability has been proposed by many researchers (Y. Chen, Li, Kilgour, & Hipel, 2008; Flores & Clay Whybark, 1986; Ramanathan, 2006). The criteria to modify the classification depend on the goal of the classification and normally not on the SKU classification technique only. Therefore, over the last decade several papers have focused on how to improve these inventory classification techniques. There also has been some research conducted to develop the classification techniques and inventory control policy. The inventory control policy covers inventory management elements such as lead time, backlog cost, holding cost, set up cost, overhead cost, inventory budget, warehouse space, etc.

1.2. Problem Statement

There are some disadvantages in ABC grouping and control techniques: 1) We cannot see the clear illustration in the literature to identify the service level for each group based on Teunter, et al. (2010); 2) Grouping is made separately from service level decision; 3) The available budget space has not been considered in study, so there is no guarantee that the two steps above are always feasible; and 4) Though the service level and grouping are important, warehouse space must also be considered. There are no existing studies in this field which include warehouse space in the model.

1.3. Research Objective

The main objective of the study is to improve inventory management to be more efficient. The study aims to help inventory managers make informed decisions on SKUs assignment and set service levels for each inventory group within a limited inventory budget and warehouse space.

The specific aims of the study are to:

- Maximize the net profit of company
- Find the optimal service level for ABC group within available inventory budget and warehouse space
- Find the optimal number of inventory groups and service level for each group within available inventory budget and warehouse space
- Compare the traditional ABC model with an optimal ABC model and an optimal classification

1.4. Scope of study

This study is conducted to find the best inventory classification model among three models; the traditional ABC model, the optimal ABC model, and the optimal inventory classification model. To prevent the biased result by company type, the experiment examines the generated data which can apply to any business types. Due to the limited time, the study chose the generated data of 1,000 SKUs based on the ABC principle for examination.

Chapter 2

Literature review

There are many studies in the literature review that focus on inventory grouping; however, the ABC inventory classification is very popular for researchers. Those studies fall into two types: inventory classification only, and inventory classification and control.

2.1. Previous model on inventory classification

There are many approaches were conducted to handle this multi-criteria inventory classification (MCIC). There have some methodologies such as the genetic algorithm (Lei, et al. 2005), the artificial neural network (ANN) (Partovi and Anandarajan, 2002), the joint criteria matrix (Flores and Whybark, 1987) , the clustering procedure (Fariborz Y Partovi and Hopton, 1994), the analytic hierarchy process(AHP) (Partovi and Hopton, 1994; Puente et al., 2002) , the fuzzy set theory (Puente et al., 2002), the principal component analysis (Chu, et al., 2008), the distance-based multi-criteria consensus framework with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) model (Bhattacharya, Sarkar, & Mukherjee, 2007) the fuzzy AHP (Cakir & Canbolat, 2008),the case-based distance model (Y. Chen et al., 2008), the particle swarm optimization method (Tsai and Yeh, 2008),the ABC–fuzzy classification method (Chu et al., 2008),the rule-based inference system (Rezaei and Dowlatshahi, 2010), the weighted linear optimization (J.-X. Chen, 2011; Hadi-Vencheh, 2010; Ng, 2007; Ramanathan, 2006; Zhou and Fan, 2007; Torabi et al., 2012)

Table 2.1 Previous model in Inventory classification

Year	Model Proposed	Author
1987	the joint criteria matrix	Flore and Whyback
1994	the clustering procedure	Fariborz and Hopton
1994	the analytic hierarchy process(AHP)	Fariborz and Hopton
2002	the artificial neural network (ANN)	Fariborz and Anandarajan
2002	the fuzzy set theory	Puente et al.

Year	Model Proposed	Author
2005	the genetic algorithm	Chen and Zhou
2007	technique for order preference by similarity to ideal solution (TOPSIS)	Bhattacharya
2006	the weighted linear optimization	Ramanathan
2007	the fuzzy AHP	Cakir and Canbolat
2008	the principal component	Chu and Liang
2008	the case-based distance model	Chen, and Kilgour
2008	the particle swarms optimization method	Tsai and Yeh
2008	the ABC–fuzzy classification method	Chu et al.
2010	the rule-based inference system	Rezaei

2.2. Inventory classification

Studies without inventory control place emphasis on single and multi-criteria classifications. The studies focus on single inventory classification that is made separately from another criterion. The value of each SKU's criteria is varied; as a result, focusing on single criteria is not accurate. Ramanathan (2006) conducted a research for ABC inventory classification with multiple criteria by using weighted linear optimization, which is called the R-model. It calls a DEA like-model. This approach generates the overall performance score with weighted linear values from all criterions such as annual dollar usage, lead time, critical factor, and average unit cost. Then, the inventory is classed based on the weighted score. The first extended research conducted to handle the R-model problem that might judge the item by its value which course the high value of unimportance criteria may classify in class A was conduct by (Zhou and Fan, 2007) as researchers known as ZF model. The composite index is more reasonable since it included some balancing features. It still shows the disadvantage in self-estimation since each item uses a set of weight in R-model and ZF-model which differ from one item to another item. As a result, the generated performance score from all items is less comparable. To eliminate some disadvantages in the R-model and ZF-model, the new model was proposed by (J.-X. Chen, 2011). They determined two common sets of criteria weights and aggregates, which result in two performance scores in the R-model and ZF-model senses for each item without any subjectivity. Ng (2007) explored the study more on DEA like model which call Ng-model which calculate the aggregation score for all classification criterions without a linear optimizer. Hadi-Vencheh (2010) led the research on MCIC by extending the Ng-model for the purpose of maximizing the performance score. It was solved in the nonlinear program. The traditional R-model can generate the performance score only for quantitative data, so the extended study to make the R-model be able to handle both quantitative and qualitative data was conducted by using some concepts in the current imprecise DEA (IDEA) models; and then it was applied for an existing classification containing both quantitative and qualitative criteria. (Torabi et al., 2012)

Table 2.2 Summary of some previous studies on inventory classification only adapted from (Millstein et al., 2014)

Author	Type		Objective Function	Criteria	Model Formulation		Budget Constraint	Number of Optimized Group	Management Overhead Cost	Space Constraint
	Propose	Extend		Multiple	Linear	Non linear				
Ramanathan (2006) and R-mode	Yes		Maximize Performance Score	Yes	Yes		No	No	No	No
Zhou, L. Fan (2007) and ZF -model		Yes (R-Model)	Minimize bad index	Yes	Yes		No	No	No	No
Wan Lung (2007) and Ng -model	Yes		Maximize Performance Score	Yes	Yes		No	No	No	No
Hadi-Vencheh (2010)		Yes (Ng-model)	Maximize Performance Score	Yes		Yes	No	No	No	No
Chen (2011)	Yes		Maximize Performance Score	Yes	Yes		No	No	No	No
Torabi ,Hatefi, and Pay (2012)		Yes (DEA-like-model)	Maximize Performance Score	Yes	Yes		No	No	No	No
Jaehun Park (2014)	Yes (CE-WLO)		Maximize Performance Score	Yes	Yes		No	No	No	No

2.3. Inventory classification and control

More advanced research in ABC analysis was conducted to find the relationship between inventory classification and control. It could be possible for the real life practice because there are many problems taken in the study beyond classification. The study that explored minimizing total inventory cost using a single criterion is found in Crouch and Oglesby (1978). They generate the model by assuming the holding cost and set up cost are the same for all items. Their model is formed as a nonlinear model. Chakravarty (1981) conducted the study on multi-item inventory aggregation into groups with the objective of minimizing the cost of ordering and holding. They found the optimal grouping by placing the order of items based on the product of demand rate and holding cost. After that, they assigned common ordering for each group. They then proposed a new model to minimize cost while maximizing service level by deciding which class should have highest/lowest service level with the assumption that reorder quantity is constant. The fill rate (alternative metric) has been considered as a new classification criterion. (Teunter et al., 2010).

One recent study developed an optimization model to find the optimal number of inventory group and service level for each group while considering the available inventory budget and management overhead cost. The overhead cost of their study was set to be constant. The objective function is set to maximize net profit which was calculated by subtracting the total overhead cost from total gross profit. Their study used Mixed Integer Linear Programming to solve the problem. The problem was solved by CPLEX. They assigned SKUs in more than three groups with specified service level (fill rate) for each group to maximize the total profit. Instead of three groups, their study suggested to class SKUs in eight groups. The solution provided by their model improves company profit by 3.85%. Mitchell A.'s approach provides more benefit to a company; however, to apply in real life, the thousands of SKUs need to be reassigned again which led to many unexpected problems and more expenses (Millstein et al., 2014)

Table 2.3 Summary of some previous studies on inventory classification and control adapted from (Millstein et al., 2014)

Author	Objective Function	Criteria		Model Formulation		Budget Constraint	MOH Cost	Optimal Number of Group	Space Constraint
		Single	Multiple	Linear	Non-Linear				
Crouch and Oglesby (1978)	Minimize cost	Yes			Yes	No	No	No	No
Chakravarty (1981)	Minimize cost	Yes		Yes		No	No	No	No
Teunter et al. (2010)	Minimize cost	Yes			Yes	No	No	No	No
Mitchell A. et al. (2014)	Maximize Profit	Yes	Yes	Yes		Yes	Yes	Yes	No
Our Study	**Maximize Profit**	**Yes**		**Yes**		**Yes**	**Yes**	**Yes**	**Yes**

MOH cost: Management overhead Cost

There was no warehouse space available constraint included in those studies above; as a result, optimizing inventory and control with space constraint would be a new contribution to research in the area.

Our study is conducted to maximize the net profit by using linear programming. The model considers an inventory budget, management overhead, warehouse space, and optimal number of inventory groups.

Chapter 3

Methodology

This study develops two different models. First an optimal ABC model is built to find an optimal service level for group A, B, and C within a limited inventory budget and provided warehouse space. A single criterion, annual dollar usage, is kept the same as in the ABC inventory classification principle. Second, an optimal inventory classification model is built to find the optimal number of inventory groups and assigned service levels for each group within a limited inventory budget and provided warehouse space. Both models are built to maximize the profit. They are formulated as a mixed integer linear program (MILP). CPLEX is chosen to solve these models.

This study presents and compares three inventory classification models as follow:

- A traditional ABC inventory classification model
- An optimal ABC model
- An optimal classification model

3.1 The traditional ABC model

This model classifies the inventory based on annual usage volume. The highest 20% of items are given the class A while 30% and 50% are classed as B and C, respectively (Flores and Whybark, 1986). Moreover, in real life, the inventory budget and warehouse space are limited, so the basic service level is not always feasible. Some inventory managers try to adapt the service level to be feasible within the limited inventory budget and warehouse space. However, it cannot guarantee that this service level is an optimal service level.

A process of finding the service level of a traditional ABC model and a proposed optimal ABC model is presented in Figure 3.1.

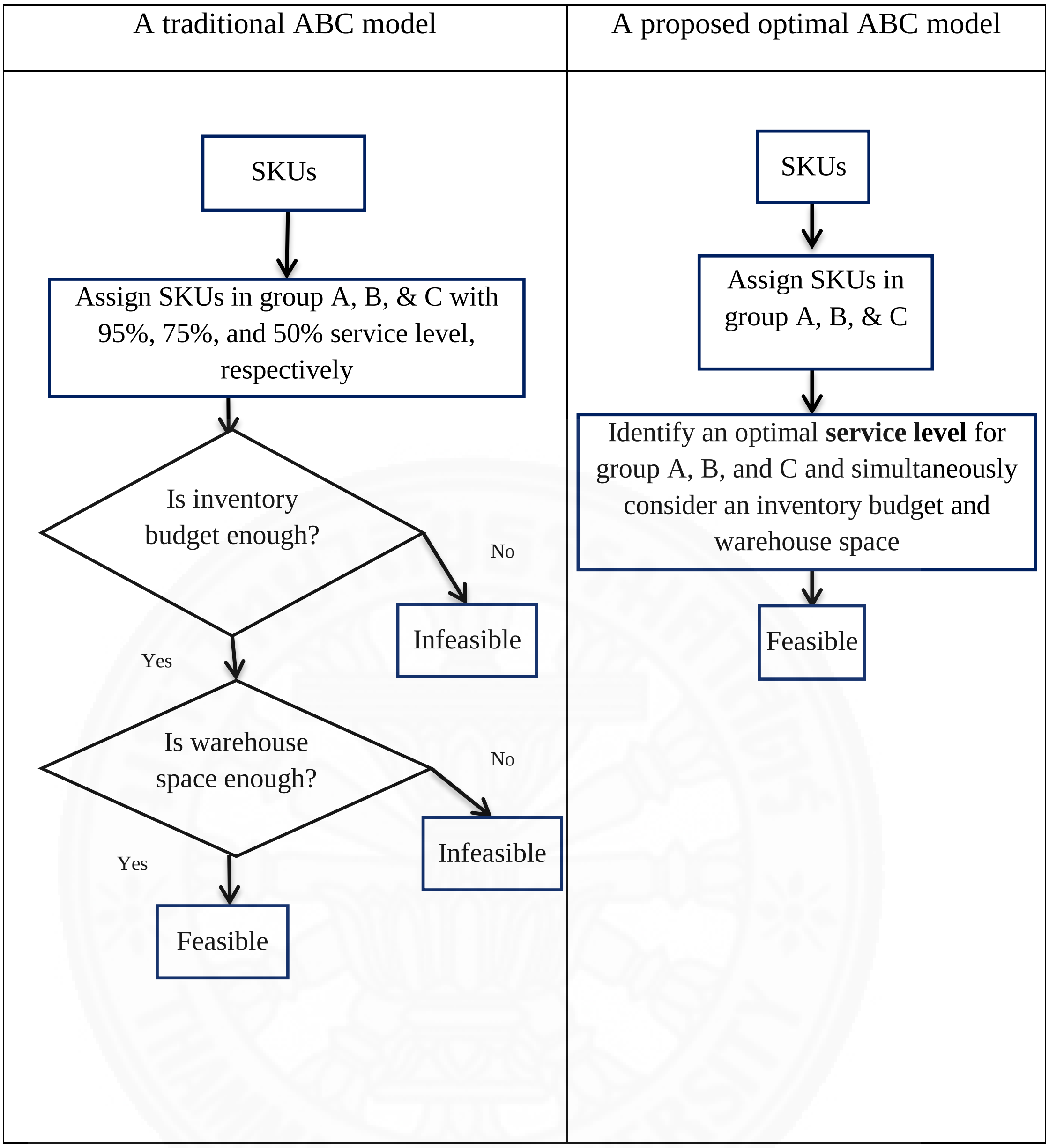

Figure 3.1 The process of the traditional ABC model and a proposed optimal ABC model

3.2 The optimal ABC model

The classification of SKUs based on the annual usage volume uses the same rule as in the traditional ABC model. This model finds the optimal service level for inventory group A, B, and C within limited inventory budget and warehouse space. A model is built to maximize the net profit of the company. This model is capable of assisting the inventory manager in choosing the optimal service level with adjustable inventory budget and warehouse space depending on the set inventory policy. This optimization has been formulated as mixed integer linear programming (MILP).

This model is capable of choosing an optimal service level in all situations when the inventory budget and warehouse space are tight. The inventory managers can guarantee that the set of service level for each group is optimal.

Notation

NA: number of inventory items in group A (SKUs)

NB: number of inventory items in group B (SKUs)

NC: number of inventory items in group C (SKUs)

MA: maximum number of inventory group A

MB: maximum number of inventory group B

MC: maximum number of inventory group C

d_{ia}: mean of monthly demand of SKU for ia = 1,…, NA

d_{ib}: mean of monthly demand of SKU for ib = 1,…, NB

d_{ic}: mean of monthly demand of SKU for ic = 1,…, NC

σ_{ia} : standard deviation of monthly demand of SKU for ia = 1,…, NA

σ_{ib} : standard deviation of monthly demand of SKU for ib = 1,…, NB

σ_{ic} : standard deviation of monthly demand of SKU for ic = 1,…, NC

g_{ia}: net profit per unit of SKU for ia = 1,…, NA

g_{ib}: net profit per unit of SKU for ib = 1,…, NB

g_{ic}: net profit per unit of SKU for ic = 1,…, NC

c_{ia}: inventory holding cost per unit SKU for ia = 1,…, NA

c_{ib}: inventory holding cost per unit SKU for ib = 1,…, NB

c_{ic}: inventory holding cost per unit SKU for ic = 1,…, NC

z_{ja}: z-value associated with group for ja = 1,…, MA

z_{jb}: z-value associated with group for jb = 1,…, MB

z_{jc}: z-value associated with group for jc = 1,…, MC

s_{ja}: service level associated with group for ja = 1,…, MA

s_{jb}: service level associated with group for jb = 1,…, MB

s_{jc} : service level associated with group for jc = 1,…, MC

o_{ja}: overhead head group A with group for ja = 1,…, MA

o_{jb}: overhead head group B with group for jb = 1,…, MB

o_{jc}: overhead head group C with group for jc = 1,…, MC

B: planned inventory spending budget

IP_{ia}: maximum number of item i can store with 1 pallet for ia = 1,…, NA

IP_{ib}: maximum number of item i can store with 1 pallet for ib = 1,…, NB

IP_{ic}: maximum number of item i can store with 1 pallet for ic = 1,…, NC

ATS: total number of pallet can store in provided space

Decision variable

yA_{ja} = 1 if inventory group ja is selected, and 0 for ja = 1,…, MA

yB_{jb} = 1 if inventory group jb is selected, and 0 for jb = 1,…, MB

yC_{jc} = 1 if inventory group jc is selected, and 0 for jc = 1,…, MC

xA_{iaja} = 1: if SKU ia is assigned to group ja for ia = 1,…, NA and ja = 1,…, MA

xB_{ibjb} = 1: if SKU ib is assigned to group jb for ib = 1,…, NB and jb = 1,…, MB

xC_{icjc} = 1: if SKU ic is assigned to group jc for ic = 1,…, NC and jc = 1,…, MC

$v_{ia} \geq 0$: inventory level of SKU for ia = 1,…, NA

$v_{ib} \geq 0$: inventory level of SKU for ib = 1,…, NB

$v_{ic} \geq 0$: inventory level of SKU for ic = 1,…, NC

Objective function

Maximize

$$\sum_{ia=1}^{NA}\sum_{ja=1}^{MA} g_{ia}d_{ia}s_{ja}xA_{iaja} + \sum_{ib=1}^{NB}\sum_{jb=1}^{MB} g_{ib}d_{ib}s_{jb}xB_{ibjb} + \sum_{ic=1}^{NC}\sum_{jc=1}^{MC} g_{ic}d_{ic}s_{jc}xC_{icjc}$$

$$- \left(\sum_{j=1}^{MA} o_{ja}y_{ja} + \sum_{j=1}^{MB} o_{jb}y_{jb} + \sum_{j=1}^{MC} o_{jc}yA_{jc}\right) \qquad (1)$$

or

$$\sum_{ia=1}^{NA}\sum_{ja=1}^{MA} g_{ia}d_{ia}s_{ja}xA_{iaja} + \sum_{ib=1}^{NB}\sum_{jb=1}^{MB} g_{ib}d_{ib}s_{jb}xB_{ibjb} + \sum_{ic=1}^{NC}\sum_{jc=1}^{MC} g_{ic}d_{ic}s_{jc}xC_{icjc}$$

$$- (o_{ja} + o_{jb} + o_{jc}) \qquad (1)$$

Constraints

$$\sum_{ja=1}^{MA} xA_{iaja} = 1, \qquad \forall ia = 1,.., NA \qquad (2)$$

$$\sum_{jb=1}^{MB} xB_{ibjb} = 1, \qquad \forall ib = 1,.., NB \qquad (3)$$

$$\sum_{jc=1}^{MC} xC_{icjc} = 1, \qquad \forall ic = 1,.., NC \qquad (4)$$

$$\sum_{ia=1}^{NA} xA_{iaja} = NAy_{ja}, \qquad \forall ja = 1,\dots, MA \qquad (5)$$

$$\sum_{ib=1}^{NB} xB_{ibjb} = NBy_{jb}, \qquad \forall jb = 1,\dots, MB \qquad (6)$$

$$\sum_{ic=1}^{NC} xC_{icjc} = NCy_{jc}, \qquad \forall jc = 1,\dots, MC \qquad (7)$$

$$v_{ia} = \sum_{ja=1}^{MA} d_{ia}l_{ia}xA_{iaja} + \sum_{ja=1}^{MA} z_{ja}\sigma_{ia}\sqrt{l_{ia}xA_{iaja}}, \qquad \forall ia = 1,.., NA \qquad (8)$$

$$v_{ib} = \sum_{jb=1}^{MB} d_{ib}l_{ib}xB_{ibjb} + \sum_{jb=1}^{MB} z_{jb}\sigma_{ib}\sqrt{l_{ib}xB_{ibjb}}, \qquad \forall ib = 1,.., NB \qquad (9)$$

$$v_{ic} = \sum_{jc=1}^{MC} d_{ic}l_{ic}xC_{icjc} + \sum_{jc=1}^{MC} z_{jc}\sigma_{ic}\sqrt{l_{ic}xC_{icjc}}, \qquad \forall ic = 1,.., NC \qquad (10)$$

$$\sum_{ia=1}^{NA} c_{ia}v_{ia} + \sum_{ib=1}^{NB} c_{ib}v_{ib} + \sum_{ic=1}^{NC} c_{ic}v_{ic} \leq B \qquad (11)$$

$$\sum_{ia=1}^{NA}\frac{v_{ia}}{IP_{ia}} + \sum_{ib=1}^{NB}\frac{v_{ib}}{IP_{ib}} + \sum_{ic=1}^{NC}\frac{v_{ic}}{IP_{ic}} \leq ATS \qquad (12)$$

$$v_{ia} \geq 0, \qquad \forall ia = 1,..., NA \qquad (13)$$

$v_{ib} \geq 0,$ $\forall ib = 1,.., NB$ (14)

$v_{ic} \geq 0,$ $\forall ic = 1,.., NC$ (15)

$xA_{iaja} = [0,1],$ $\forall ia = 1,.., NA ; \forall ja = 1,\ldots, MA$ (16)

$xB_{ibjb} = [0,1],$ $\forall ib = 1,.., NB ; \forall jb = 1,\ldots, MB$ (17)

$xC_{icjc} = [0,1],$ $\forall ic = 1,.., NC ; \forall jc = 1,\ldots, MC$ (18)

$yA_{ja} = [0,1],$ $\forall ja = 1,\ldots, MA$ (19)

$yB_{jb} = [0,1],$ $\forall jb = 1,\ldots, MB$ (20)

$yC_{jc} = [0,1],$ $\forall jc = 1,\ldots, MC$ (21)

The objective function (1) is set to maximize the total profit, calculated by the summation of the gross profit generated by groups A, B, and C. The service level is treated as a fill rate to calculate the satisfied demand by inventory level. The fill rate has also been used by other researchers such as Teunter et al. (2010) and Millstein et al. (2014). Constraints (2), (3), and (4) force the model to assign an SKU into one group for group A, B, and C, respectively. Constraints (5), (6), and (7) enforce that only an open group is allowed to be assigned an SKU. Constraints (8), (9), and (10) calculate the inventory level of SKUs in group A, B, and C, respectively by the summation of demand during the lead time and safety stock (in the case of uncertain demand and certain lead time) (Ballou, 2007). Constraint (11) ensures that the inventory budget is higher than or equals the total inventory holding cost. Constraint (12) ensures that the total space required to store all SKUs does not exceed the available warehouse space. Constraints (13) through (21) identify the domains of decision variables.

This model is able to choose the optimal service level for group A, B, and C in all situations when the inventory budget and warehouse space are tight or big.

3.3 The optimal inventory classification model

The optimizing both inventory grouping and control model which considers optimal service level, inventory budget, warehouse space, management overhead cost, and optimal number of inventory groups has been formulated as mixed integer linear programming (MILP). This model is built to maximize net profit. The model assigns SKUs in groups based on the net profit earned by an individual SKU. The SKU with higher net profit earning is grouped in a higher service level group. The previous study which this model extended from focused only on the inventory budget and management overhead cost in order to find the optimal assignment of SKUs, number of inventory group and optimal service level (Millstein et al., 2014). The warehouse space which is a concern of global trend due to the population growth is included in models 3.2 and 3.3. Though inventory managers reserve huge inventory budget, they cannot store items over the warehouse capacity, therefore it is necessary to include warehouse space in the model.

Notation.

N: number of inventory items (SKUs)

M: maximum number of inventory groups

d_i: mean of monthly demand of SKU i = 1,…, N

σ_i : standard deviation of monthly demand of SKU i = 1,…, N

g_i: net profit per unit of SKU i = 1,…, N

c_i: inventory holding cost per unit SKU i = 1,…, N

z_i: z-value associated with group j = 1,…, M

s_j: service level associated with group j = 1,…, M

o_j: fixed management overhead cost for inventory group j = 1,…, M

B: planned inventory spending budget

IP_i: maximum number of item i can store with 1 pallet i = 1,…, N

ATS: total number of pallets that can be store in provided space

Decision variable

y_j = 1 if inventory group j is selected, and 0 for selected for j = 1,…, M

x_{ij} = 1: if SKU i is assigned to group j for i = 1,…, N and j = 1,…, M

v_i ≥0 : inventory level of SKU i = 1,…, N

Objective function

Maximize $\sum_{i=1}^{N}\sum_{j=1}^{M} g_i d_i s_j x_{ij}$ - $\sum_{j=1}^{M} o_j y_j$ (1)

Constraints

$\sum_{j=1}^{M} x_{ij} \leq 1,$ ∀i = 1,.., N (2)

$\sum_{i=1}^{N} x_{ij} \leq N y_j,$ ∀j = 1,…, M (3)

$v_i = \sum_{j=1}^{M} d_i l_i x_{ij} + \sum_{j=1}^{M} z_i \sigma_i \sqrt{l_i x_{ij}},$ ∀i = 1,.., N (4)

$\sum_{i=1}^{N} c_i v_i \leq B$ (5)

$\sum_{i=1}^{N} \frac{v_i}{IP_i} \leq$ ATS (6)

$v_i \geq 0,$ ∀i = 1,.., N (7)

x_{ij} = [0,1], ∀i = 1,.., N ; ∀j = 1,…, M (8)

y_j = [0,1], ∀j = 1,…, M (9)

The objective function (1) of this MILP model is to maximize the total net profit by subtracting the total management overhead cost from the total gross profit. Profit in group *j* is computed by summation average demand of SKU *i* multiplied by the profit of SKU *i* and multiplied with service level which treated as a fill rate of group *j*. One SKU assigned to the only group is illustrated in constraint (2). SKU *i* is not feasible to assign in any group. Constraint (3) forces the model to assign the SKU in only opened group *j*. Constraint (4) calculates the inventory level of SKU *i* in the standard way as the summation of mean demand plus safety stock. (Ballou, 2007).

Constraint (5) ensures that the summation of all SKU holding cost is not over a planned inventory spending budget. Constraint (6) forces the model to not let the total required space exceed the total assigned space in the warehouse.

Chapter 4

Computational Result

This study compares a traditional ABC model, an optimal ABC model, and an optimal inventory classification model. The profits found by these three models from different scenario are compared. The service level for each group is also emphasized.

In the calculations, the potential 108 different groups and service levels from 1% to 99% (with the increment of 1%), include nine service levels from 99.1% to 99.9% (with the increment of 0.1%). We solve the MILP models presented in Section 3 by the branch and cut (B&C) method in CPLEX 12.3 on a laptop PC with 2.7 GHz CPU speed and 8 GB memory. CPLEX spent about 2mn to find the optimal solution (and prove optimality).

4.1 Data preparation

The study is conducted on 1,000 generated SKUs based on Pareto principle. The property of SKUs is shown below.

- Unit Cost

  Uniform range between 50USD to 1,100USD

  Group A from 750 to 1,100 (200 SKU)

  Group B from 300 to 749 (300 SKU)

  Group C from 50 to 299 (500 SKU)
- Profit

  Use uniform 10% to 30% of unit cost

  Group A 20% to 30%

  Group B 15% to 25%

  Group C 10% to 20%
- Lead time

  Use uniform range between 2weeks to 3weeks
- Holding Cost

20% of unit cost per year, so monthly divides by 12 (In theory, holding cost could be from 5% to 20% of unit cost per year. We chose 20% to make sure that our model can deal with high holding cost to produce maximum profit)

- Unit can store in one pallet

  The size of product is assumed randomly within uniform range to be between 5 units and 70 units in one pallet. It would to apply in any industry because the size of product is random. We cannot assume a big SKU is always more expensive than a small SKU.

- Mean of Monthly Demand

  The first 20% (Group A) of 1,000 SKUs uses normal distribution mean = 30, Standard Deviation = 5, then is rounded to be an integer

  The second 30% (Group B) of 1,000 SKUs uses normal distribution mean = 15, Standard Deviation = 5, then is rounded to be an integer

  The third 50% (Group C) of 1,000 SKUs uses normal distribution mean = 10, Standard Deviation = 5, then is rounded to be an integer

- Standard deviation of monthly demand

  We uniformly to generate the date range between 7% to 10% for group A and B. For inventory group C, standard deviation of monthly demand ranges from 10% to 12%.

4.2 Comparison between model 3.1 and model 3.2

There are no guarantees that a traditional ABC approach is feasible with the provided service level under the limited inventory budget and limited warehouse space. The service level of the traditional ABC approach is set separately from the inventory budget and warehouse space; as a result, the inventory manager needs to clarify that it is possible to assign within provided budget and space with related departments. In the case that the inventory budget and warehouse space are not enough for the ABC service level, the inventory managers needs to adjust the service level to be feasible. However, there are no guarantees that the service level of each group is optimal as shown in Figure 3.1.

The optimal ABC model is built to add flexibility to the traditional ABC approach in a situation of limited inventory budget and warehouse space. The model generates the optimal service levels for group A, B, and C. The result is generated and compared with the traditional ABC model in different scenarios.

4.2.1 Comparison on three scenarios

We implement the model in three scenarios, shown in Table 4.1. First, we set the inventory budget and warehouse space to be feasible with the traditional ABC which is 95%, 75%, and 50% for service level for group A, B, and C, respectively. Second, the inventory budget and warehouse is set higher to see how our model flexibly assigns the service level. Finally, the proposed model is used within a tight inventory budget and warehouse space. We set these three scenarios to see how flexible this model is in different situations compared with the traditional ABC model. These three scenarios represent when we have enough resource, huge resource, and low resource. A result from using the proposed model in these scenarios is the ability to cover the real situation which has unstable resources. The result variation based on the different scenario can represent the real life practice.

Table 4.1 Value sets for testing scenario

	Inventory Budget(USD)	Warehouse Space(pallet)
Scenario 1	104,000	500
Scenario 2	118,000	520
Scenario 3	100,000	430

In Scenario 1, the study set the inventory budget 104,000 USD and 500 pallet spaces available. By changing the traditional ABC service level to optimal service level, which is found by the MILP model, its profit improves 2.9% from 1,641,071 USD to 1,688,725 USD. Profit found by our model and the ABC traditional model is shown in Figure 4.1 and the service level is found in Table 4.2.

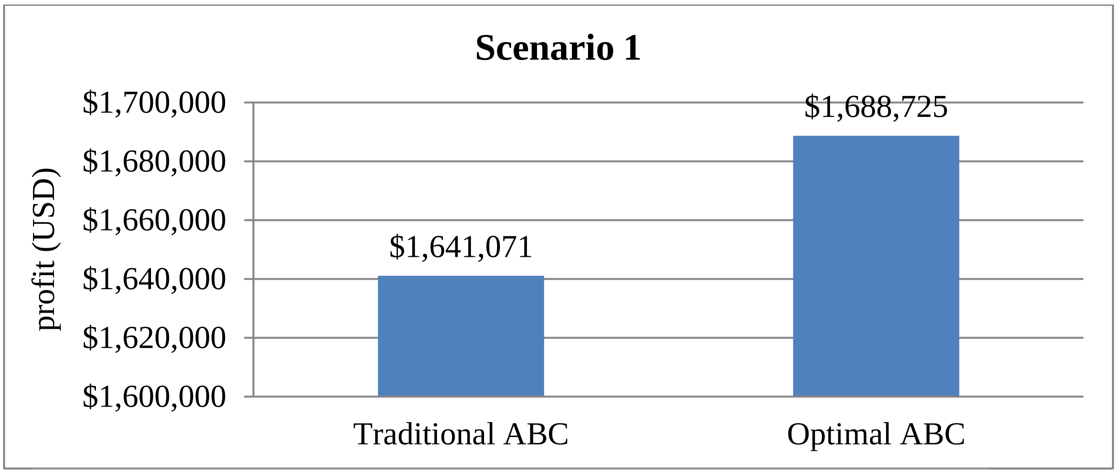

Figure 4.1 Profit comparison between the traditional ABC and the optimal ABC (Scenario 1)

Though we increase the inventory budget and warehouse space, the traditional ABC method still keeps the same service level which provides no profit improvement. However, the optimal ABC model finds an optimal service level to maximize profit. In Scenario 2, we increase the inventory budget to 118,000 USD and 520 pallet space available. The optimal ABC model improves profit 12.33% compared to the traditional ABC. Profit is shown in Figure 4.2 and service level in Table 4.2.

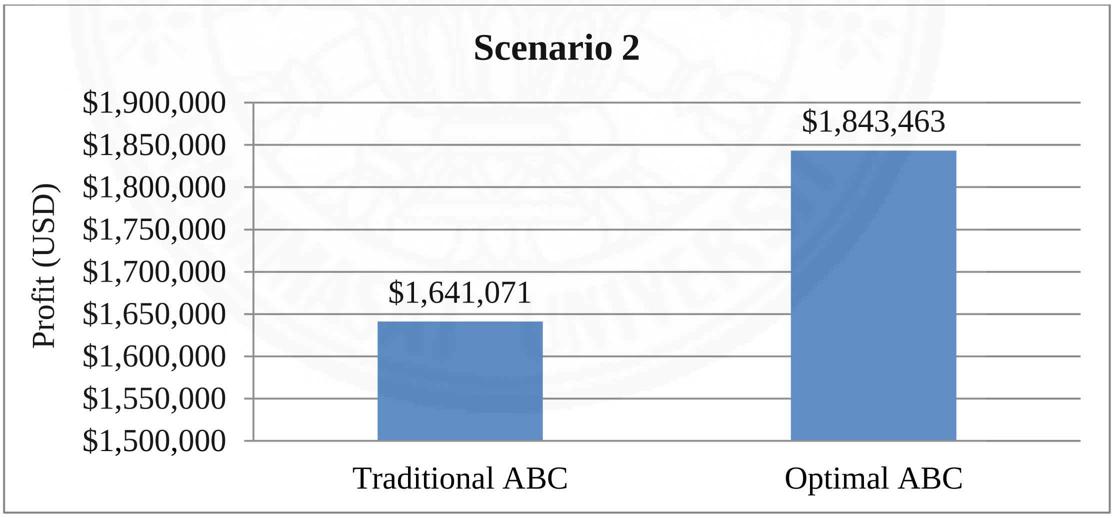

Figure 4.2 Profit comparison between the traditional ABC and optimal ABC (Scenario 2)

In Scenario 3, we decreased the inventory budget to 100,000 USD and 430 pallet spaces available. The traditional ABC model becomes infeasible if the inventory budget and warehouse space are lower than numbers provided in Scenario 1, but the optimal ABC model is still feasible and able to generate the profit of 1,584,417 USD. The optimal ABC model assigned group C to have only 1% of service level. While this allocation seems inapplicable in real life, to maximize the profit within a limited budget and warehouse space, it is an optimal solution.

Table 4.2 The service level found by traditional ABC model and optimal ABC in different scenarios

Approach	Service level (%) in Group A, B, and C		
	Scenario 1	Scenario 2	Scenario 3
Traditional ABC	95, 75, and 50	95, 75, and 50	95, 75, and 50 (infeasible)
Optimal ABC	92, 89, and 82	99.3, 99.1, and 99	89, 85, and 1

We perform an additional experiment by controlling the service level of group C to have more than 10% in the proposed model. The reason for controlling the service level is to show that our model is capable of altering condition, based on the change of inventory policy. The result shows that our model is flexible in real life with any inventory policy in different situations.

Table 4.3 The service level found by traditional ABC, optimal ABC without control and optimal ABC with control service level

	Service Level (%)		
	Traditional ABC	Optimal ABC without service level control	Optimal ABC with minimum service level control
Group A	95	89	86
Group B	75	85	83
Group C	50	1	69

The result of service level is shown in Table 4.3 and profit in Figure 4.3. The net profit provided by controlling minimum service level on our proposed model is 1,573,347 USD. It is slightly smaller than the previous experiment by only 0.7%.

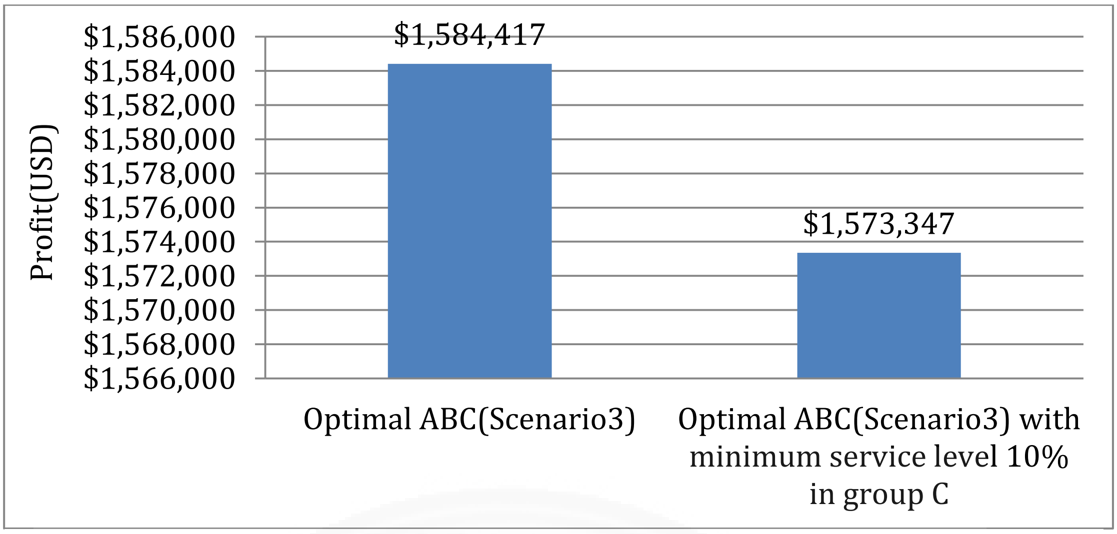

Figure 4.3 Profit comparison between the optimal ABC with and without minimum service level requirement in group C

The optimal ABC model found new service level for group A, B, and C by reducing the service level for group A from 89% to 86% and group B from 85% to 83%, making it possible for CPLEX to assign group C a higher service level.

While there is no guarantee that traditional ABC is feasible with rule 95%, 75%, and 50% of service level for groups A, B, and C, respectively in tight inventory budget and limited warehouse space, an optimal ABC can decide service level for each group flexibly to maximize profit based on available inventory budget and warehouse space. Moreover, instead of allowing the program to choose the service level freely, we can control the range of service level by adding a minimum service level in the model. It is suitable for an inventory manager to plan the inventory policy in the diverse market situation.

Insight 1. By using the optimal ABC model, the net profit increases as the inventory budget and warehouse space increase as shown in testing Scenario 2.

The optimal ABC model is flexible to assign higher service levels of each group when the inventory budget and warehouse space is high; in addition, it is capable of finding the optimal service level when there are limited warehouse space and limited inventory budget. Without the optimal ABC, it will not be straightforward to determine the optimal service level of the inventory group.

Next, we conduct experiments when an inventory budget is fixed and a warehouse space is varied, and vice versa.

4.2.2 Profit with fixed inventory budget and various spaces

This section presents a net profit comparison between a traditional ABC and optimal ABC from Model 3.1 and 3.2, respectively. Given an inventory budget of 140,000 USD and an overhead cost of 300 USD, the warehouse space is varied. Results are shown in Figure 4.4.

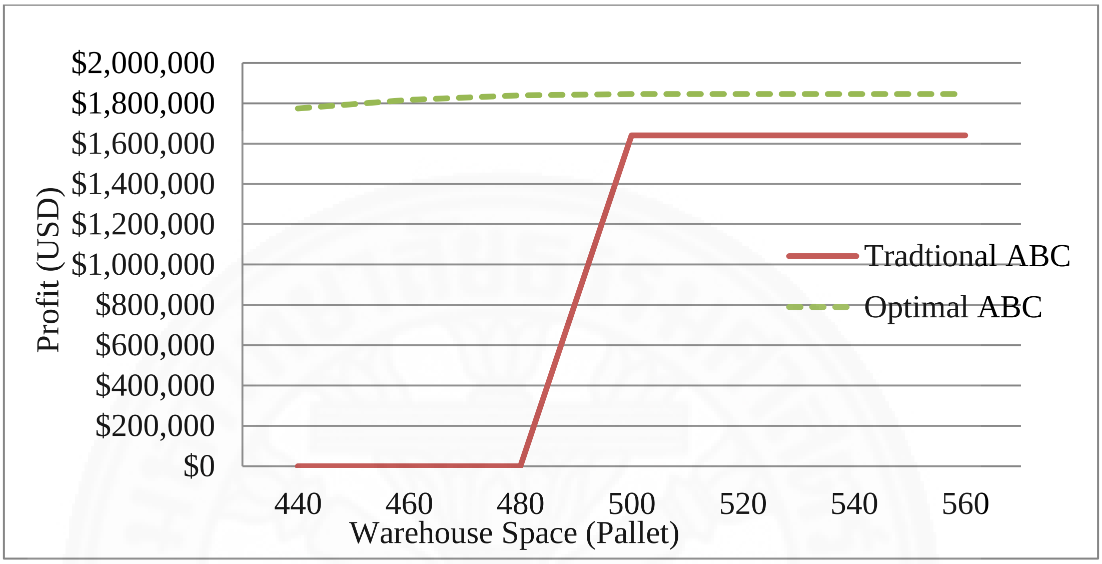

Figure 4.4 Profit comparison from a traditional ABC model and an optimal ABC model with various warehouse spaces

The graph shows the profit found by the traditional ABC model and the optimal ABC model. The traditional ABC is infeasible when the warehouse space is under 500 pallets space, while the optimal ABC model can generate the net profit. When there are a lot of resources the traditional ABC still cannot improve the profit; however, the optimal ABC can improve profit.

4.2.3 Profit with fixed space and various inventory budgets

A traditional ABC and an optimal ABC are employed with 540 pallets of warehouse space and overhead cost of 300 USD. The inventory budget is varied.

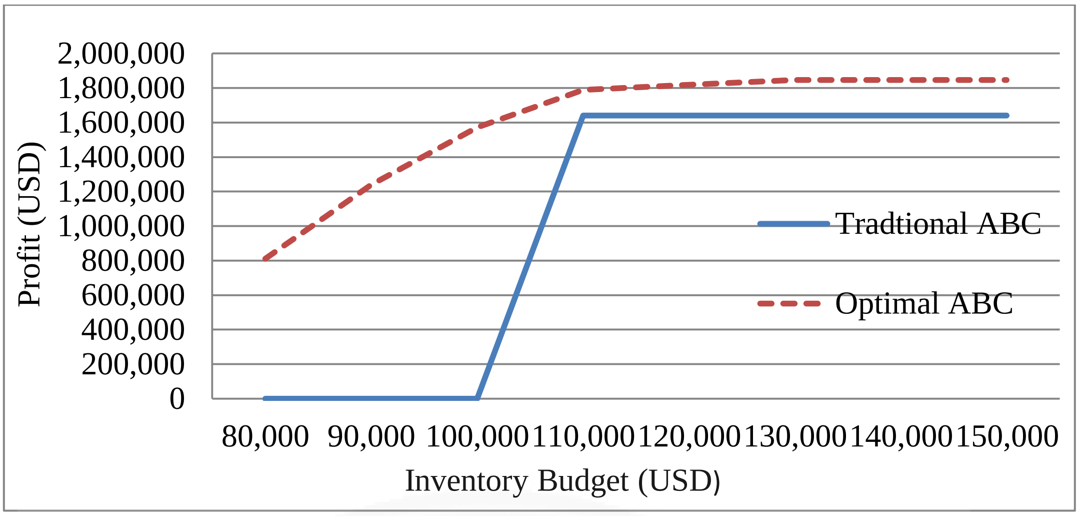

Figure 4.5 Profit comparison from the traditional ABC model and the optimal ABC model with various inventory budgets.

The graph illustrates the profit comparison between the traditional ABC model and the optimal ABC model. The traditional ABC model cannot improve the profit when the inventory budget is huge. In addition, this model is infeasible to generate the net profit when the inventory budget is smaller than required. The proposed optimal ABC model can improve the net profit when we increase the inventory budget.

To sum up, the optimal ABC model is flexible assigning service level for groups A, B and C in any situation. When there is more resource, this model can improve the profit, while the service level is adjusted to be small when the inventory budget and warehouse space are small. The optimal ABC model is better than the traditional ABC in choosing an optimal service level simultaneously with the inventory budget and warehouse space which guarantees that the set of service level is always feasible and optimal.

4.3 Comparison between model 3.1 and model 3.3

The traditional ABC model assigns SKUs into only groups A, B, and C with service level 95%, 75%, and 50%, respectively. There are no guarantees that the three inventory groups with set service levels are feasible and optimal under restricted inventory budget and warehouse space. The number of inventory group and service levels of the traditional ABC model is set separately from an inventory budget and warehouse space. The optimal inventory classification model calculates the optimal number of an inventory group within provided inventory budget and limited warehouse space.

4.3.1 Comparison on three scenarios

The comparison of the traditional ABC model and the optimal inventory classification model is conducted to see how different SKU assignments in these models are. The optimal service level and an optimal number of inventory groups are determined to maximize the profit within the limited inventory budget and available warehouse space. This section compares the generated profit from both models. The experiment is conducted on three different scenarios which are presented in Table 4.4.

Table 4.4 Value sets for testing scenario

	Inventory Budget (USD)	Warehouse Space(pallet)
Scenario 1	104,000	500
Scenario 2	118,000	520
Scenario 3	100,000	430

The first scenario is conducted on the adequate inventory budget and warehouse space for the traditional ABC model.

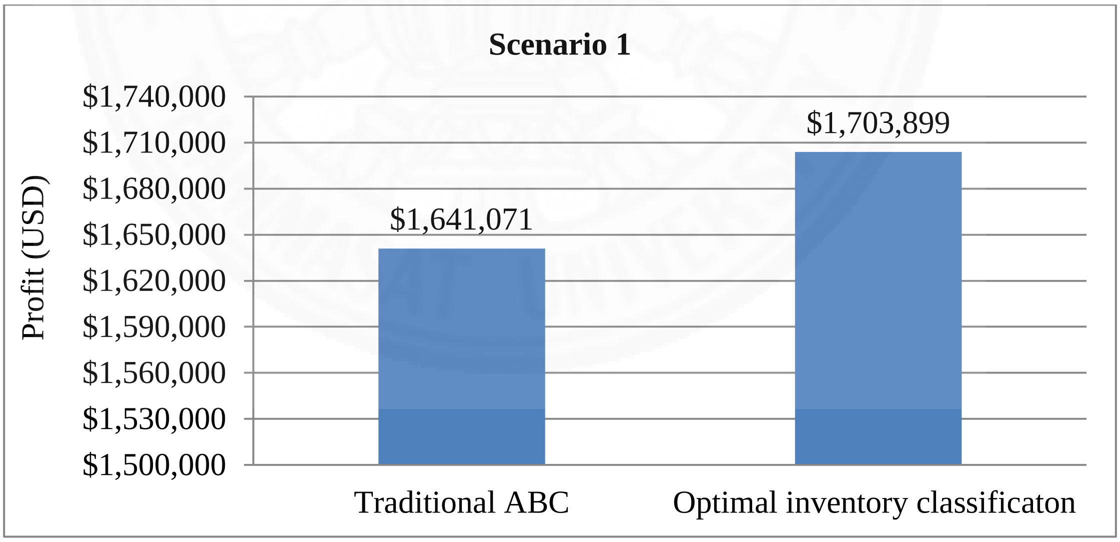

Figure 4.6 Profit comparison between the traditional ABC and the optimal inventory classification (Scenario 1)

In Scenario 1, the study sets the inventory budget at 104,000 USD and 500 pallet space available. The model yields the optimal number of groups and service levels for each group. It assigns SKUs into six groups instead of three groups. The service level of each group is 97%, 95, 93%, 90%, 87%, and 1%. By this MILP model, profit improves 3.8% from 1,641,071 USD to 1,703,899 USD. Profit and service level for each group that were found by the proposed optimal classification model and the traditional ABC model are shown in Table 4.5; and 4.6, and Figure 4.6.

Table 4.5: The optimal inventory classification and service level found by the MILP model in Scenario 1

Group with service level (%)	Number of SKUs (%)	Net Profit (USD)	Inventory Spending	Space Use (pallet)
97%	85 (8.5%)	377,241	15,483	46
95%	182 (18.2%)	420,387	21,788	85
93%	221 (22.1%)	459,893	29,741	110
90%	198 (19.8%)	357,533	26,879	111
87%	172 (17.2%)	90,338	8,573	52
1%	142(14.2%)	306	1,536	14
Total	1000 (100%)	1,703,899	104,000	419

Table 4.6 The service level found by the traditional ABC model and the optimal inventory classification in different scenario

Model	Service level (%) in inventory Group		
	Scenario 1	Scenario 2	Scenario 3
The traditional ABC	95, 75 and 50	95, 75 and 50	95, 75 and 50 (infeasible)
The optimal inventory classification	97, 95, 93, 90, 87 and 1(six groups)	99.3, 99.1 and 99 (three groups)	96, 94, 91, 87, and 1 (five groups)

In Scenario 2, we increase the inventory budget to 118,000 USD and 520 pallet space available.

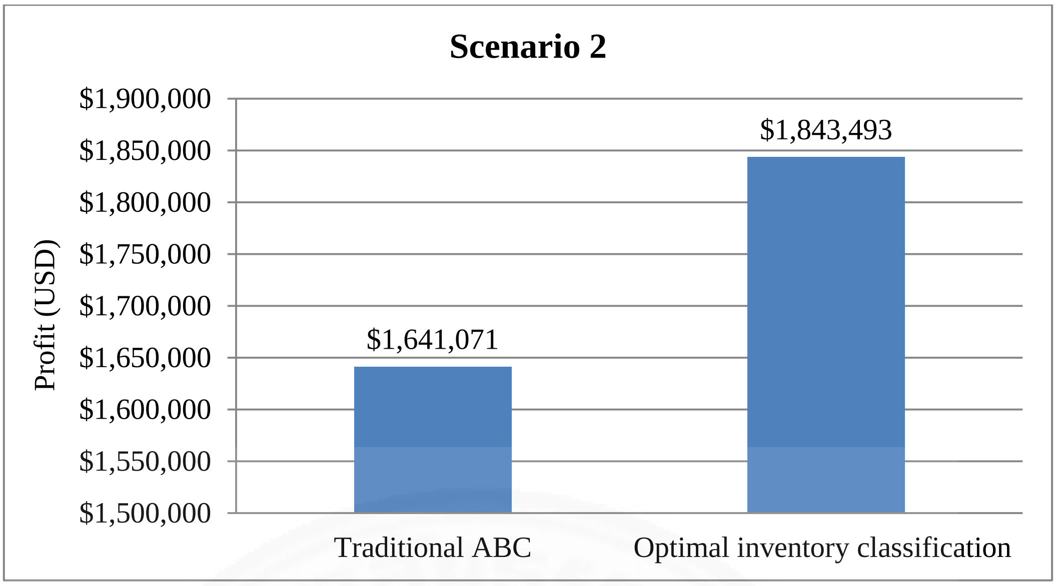

Figure 4.7 Profit comparison between the traditional ABC and the optimal inventory classification (Scenario 2)

Though the inventory budget and space are increased, the traditional ABC provides no profit improvement. The proposed optimal inventory classification model can improve profit by 12.33% from 1,641,071 USD to 1,843,493 USD. The optimal service level is shown in Table 4.6 and profit in Figure 4.7.

The traditional ABC model is infeasible if the inventory budget and warehouse space are lower than numbers provided in Scenario 1. In Scenario 3, we decreased the inventory budget to 100,000 USD and 430 pallet space available and obtained the profit of 1,621,428 USD.

The optimal number of inventory groups is an incentive to assign more than three groups when the inventory budget and warehouse space are tight. When the warehouse space is tight, there are needs of an optimal decision for SKUs assignment.

4.3.2 Profit with fixed inventory budget and various spaces

This section generates the net profit from a traditional ABC and an optimal inventory classification in Model 3.1 and 3.3, respectively with inventory budget of 140, 000 USD and overhead cost of 300 USD to see the difference of net profit when the warehouse space is varied.

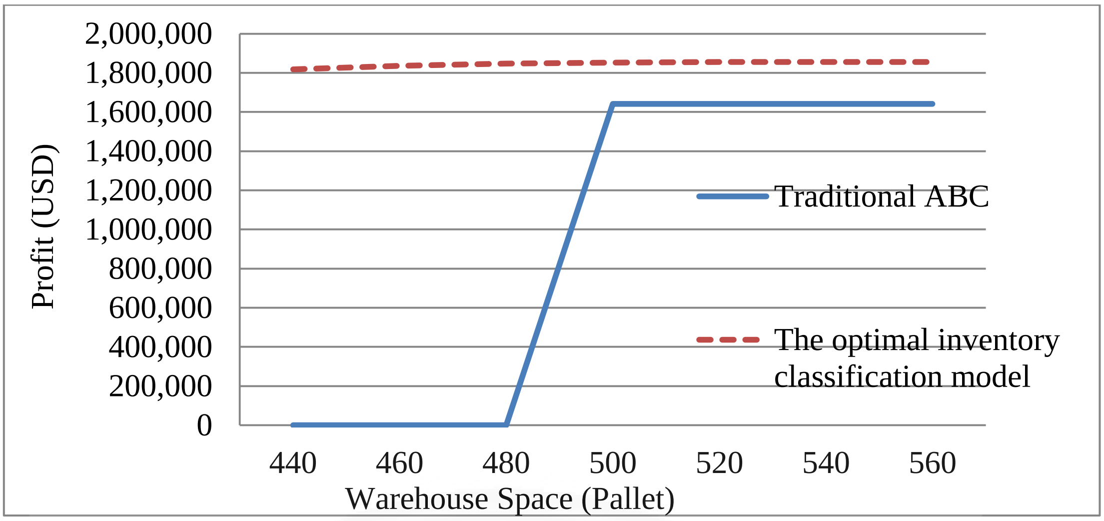

Figure 4.8 Profit comparison calculated by the traditional ABC model and the optimal inventory classification model with various warehouse space

The graph illustrates the profit generated by the traditional ABC model and the optimal inventory classification model. The traditional ABC model is infeasible to generate the profit when the warehouse space is lower than required. The optimal inventory classification model can improve the profit when the warehouse space is larger, while the traditional ABC cannot improve the profit.

4.3.3 Profit found with fixed space and various inventory budgets

The experiment generates the net profit from Model 3.1 and 3.3 with 540 pallets warehouse space and 300 overhead cost to see the difference of net profit between each model when the inventory budget is varied.

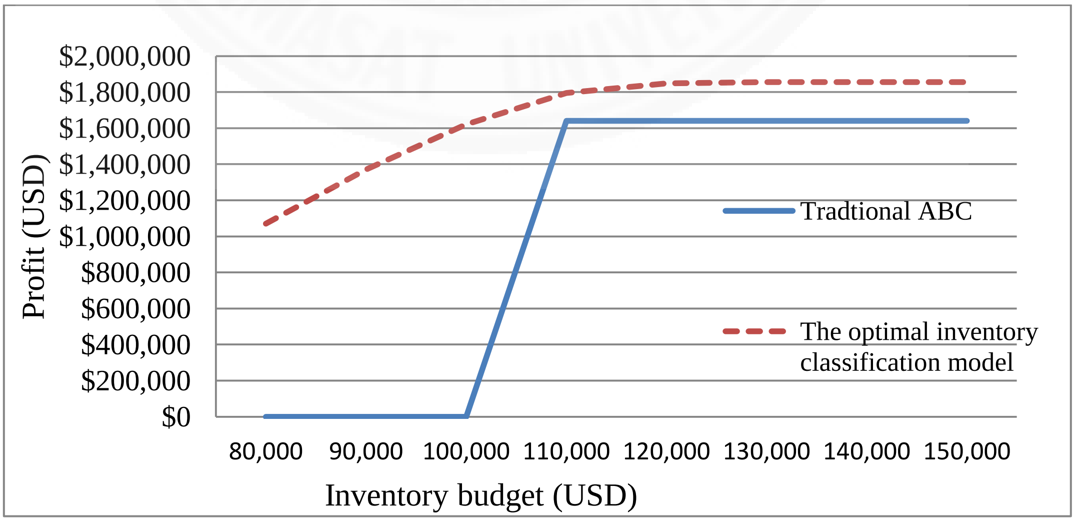

Figure 4.9 Profit comparison by the traditional ABC model and the optimal inventory classification model with various inventory budgets.

The line graph presents the profit found by the traditional ABC model and the optimal inventory classification model. The traditional ABC is infeasible to generate the profit when the inventory budget is smaller than that required. The optimal inventory classification model can improve the profit when there is more inventory budget; nevertheless, the traditional ABC model cannot improve the net profit.

4.4 Comparison between model 3.2 and model 3.3

In this section, a profit comparison of the optimal ABC model presented in Section 3.2 and the optimal inventory classification model presented in Section 3.3 is made. We use the inventory available budget 120,000 USD and 440 pallets space assigned. The management overhead cost is fixed with 300 USD per group. The profit comparison is shown in Figure 4.10.

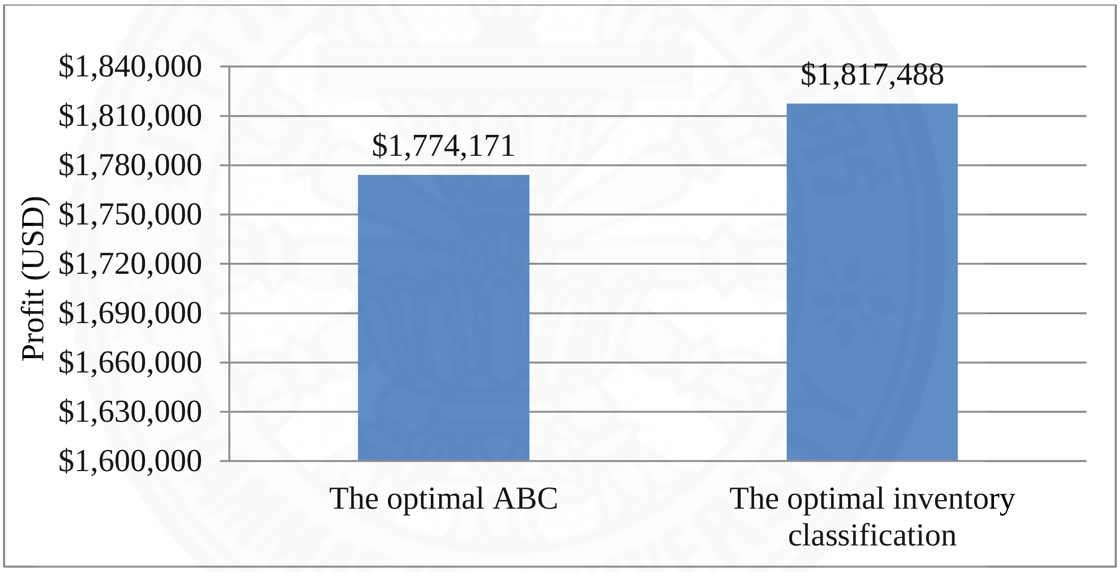

Figure 4.10 Profit comparison between the optimal ABC model and the optimal inventory classification model

The optimal inventory classification model generates a profit 1,817,488USD higher than the optimal ABC model by 2.4%. The optimal inventory classification model assigns SKUs into an optimal number of inventory groups with the optimal service level. While the optimal ABC changes only service levels for groups A, B, and C. The assignation of SKUs, service level, and profit made in each group is shown in Table 4.7 and 4.8

Table 4.7 Inventory classification and service level found by the optimal ABC model

ABC Group	Service level %	#SKU	Monthly sales	Total Profit	Space use
A	99%	200	$5,276,562	$1,298,890	222 Pallets
B	96%	300	$2,288,721	$469,420	170 Pallets
C	11%	500	$40,045	$5,861	47 Pallets

Table 4.8 The optimal inventory classification and service level found by the optimal inventory classification model

Group with service level (%)	Number of SKUs (%)	Net Profit (USD)	Inventory Spending	Space Use
99.7%	158 (15.8%)	865,931	49,688	70.53
99.1%	177 (17.7%)	493,030	32,168	93.47
98%	210 (21%)	289,237	20,629	109.69
95%	189 (18.9%)	139,821	10,288	101.68
90%	118 (11.8%)	30,820	2,695	39.40
1%	148 (14.8%)	150	743	25.22
Total	1000(100%)	1,817,488 (1,800 OC)	116,209	440

OC = Overhead cost

The number of inventory groups and assigned service level found by the optimal inventory classification model is different from the optimal ABC model. The optimal inventory classification model assigns SKUs into six different groups. The first group, with highest service level, is assigned 15.8% of total 1,000 SKUs, which has 47.64% of total profit with highest service level of 99.7%. The bottom 50% of SKUs is assigned to group C (Flores and Whybark, 1986), while the optimal inventory classification has classed about 63% of the items into five different groups with service levels of 99.1% , 98%, 95%, 90%, and 1%.

4.4.1 Additional computation on profit

The optimal ABC model presented in Sector 3.1 is compared with the optimal inventory classification model presented in Section 3.2. The comparison result focuses on profit and service level which are generated by these models. These models are calculated in two created scenarios. In the first scenario, the inventory budget is fixed with various warehouse spaces. In the second, the warehouse space is fixed with various inventory budgets. The management overhead cost is fixed on these calculations. The study also generates the optimal number of inventory groups calculated by the optimal inventory classification model.

4.4.1.1 Fixed inventory budget and various warehouse spaces

This section presents a net profit comparison between the optimal ABC and the optimal inventory classification presented in Models 3.2 and 3.3, respectively. Given an inventory budget of 120,000 USD and an overhead cost of 300 USD, the warehouse space is varied. Results are shown in Figure 4.11.

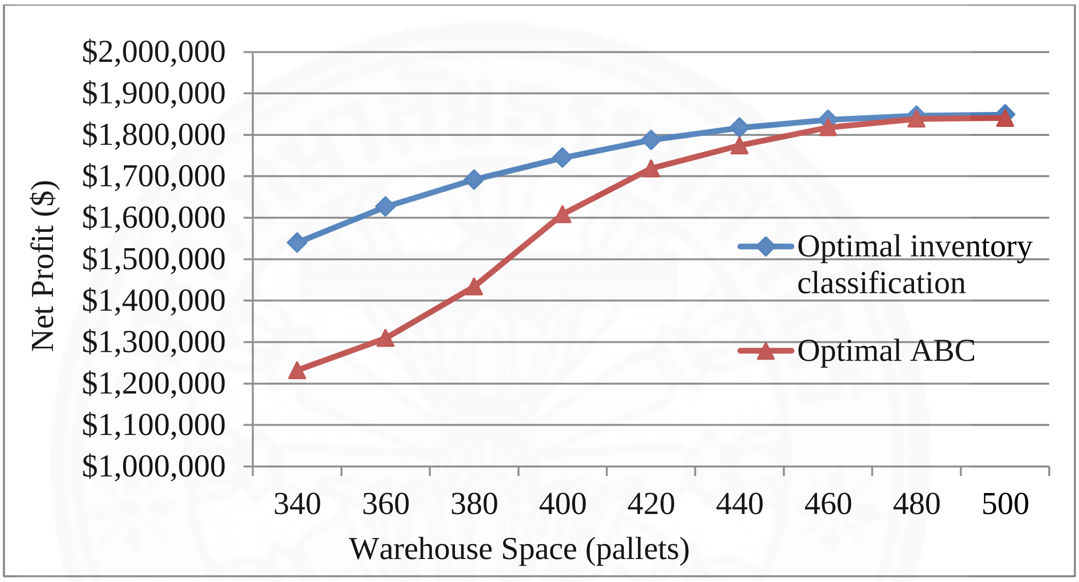

Figure 4.11 Profit comparison between the optimal inventory classification model and the optimal ABC model with various warehouse spaces

This graph shows the net profit comparison between the optimal inventory classification model and the optimal ABC model over the various warehouse spaces. The net profits found by these models are almost the same when the value of warehouse space is big. However, when the warehouse space is tight the difference of profit found by these two models is large. It shows that the optimal inventory classification model generates a better profit when there is limited warehouse space which most likely occurs in real life. The profit found by the optimal ABC model decreases dramatically when the warehouse space falls from 400 pallets space to 380 pallets space from almost 1,600,000 USD to nearly 1,400,00 USD. Nevertheless, the profit found by the optimal inventory classification model slightly drops from almost 1,750,000 USD to just less than 1,700,000 USD. The difference of just 20 pallets space affects profit generated by the optimal ABC model by 12.5%, while the profit found by the optimal inventory classification model is affected only approximately 3%.

4.4.1.2 Fixed warehouse space and various inventory budgets

This section presents a net profit comparison between the optimal ABC and the optimal inventory classification presented in Models 3.2 and 3.3, respectively. Given a warehouse space of 480 pallets and an overhead cost of 300 USD, the inventory budget is varied. Results can be seen in Figure 4.12 .

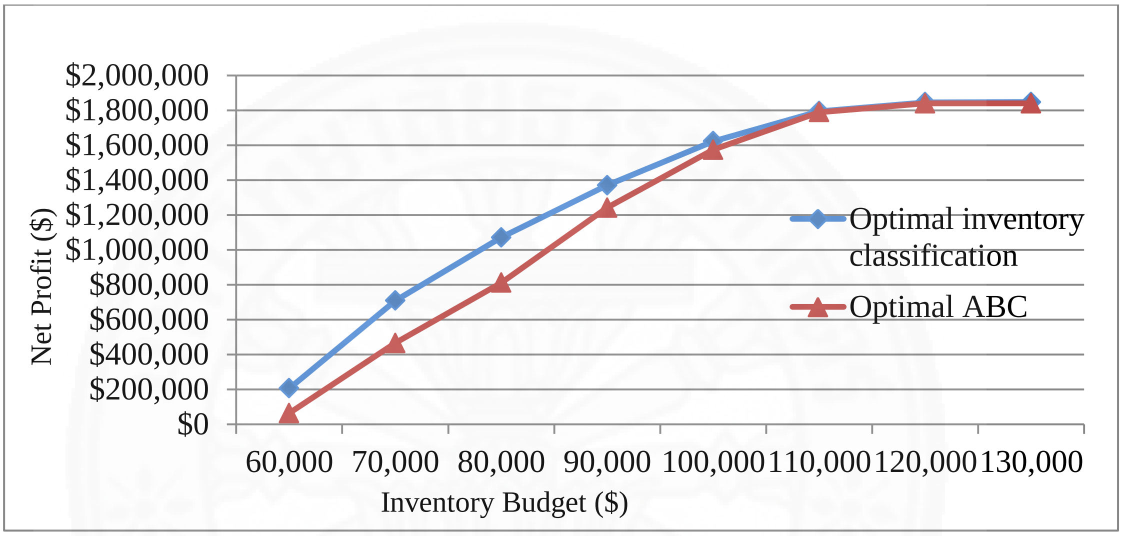

Figure 4.12 Profit comparison between the optimal inventory classification model and the optimal ABC model with various inventory budgets

This graph shows the net profit comparison between the optimal inventory classification model and the optimal ABC model when the inventory budgets is varied. The net profits found by these models are almost the same when the value of inventory budget is big. However, the optimal classification model generates a better profit when the limited inventory budget is small. The profit found by both models decreases steadily when the inventory budget falls below 110, 000 USD.

We conducted another experiment to see the profit change when the inventory budget and warehouse space are varied together. We vary an inventory budget from 700,000 USD to 1,400,000 USD by increments of 100,000 USD and warehouse space from 360 pallets to 500 pallets by increment of 20pallets. The model generated 64 different profits which are presented in Figure 4.13.

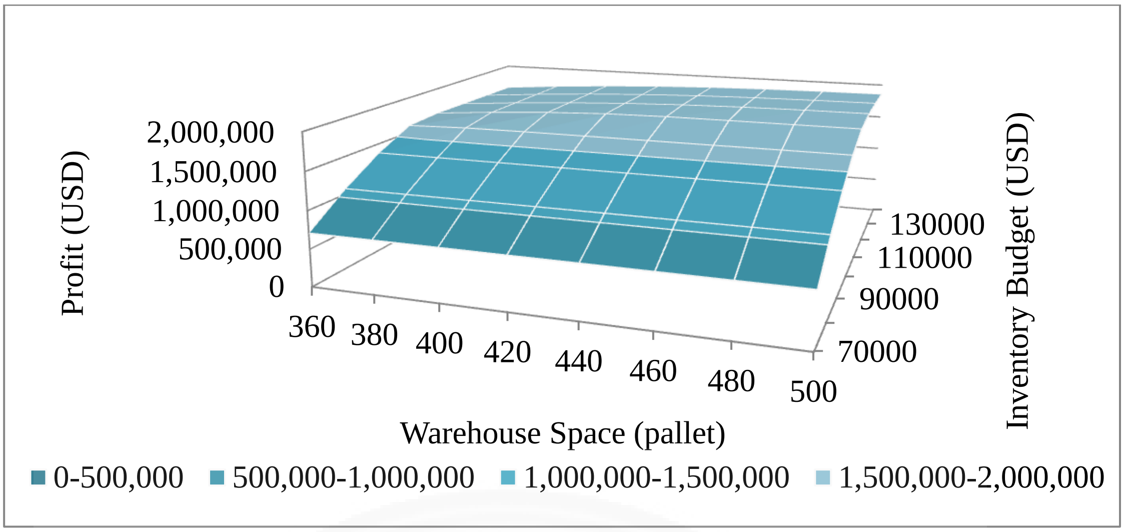

Figure 4.13 Profit comparison by the optimal inventory classification model with various inventory budgets and various warehouse spaces

This three-dimension graph illustrates that the optimal inventory classification model generates more profit when an inventory budget and warehouse space is big. However, the increment of profit is smaller and smaller when we increase inventory budget and warehouse space higher and higher. This information can help inventory manager to decide how much inventory budget and warehouse space they need to satisfy the profit target and stay within available resources. They can see how much profit they get from investing more money on the inventory budget and warehouse space.

Insight 2. The profit earning by increasing value of inventory budget and warehouse space is not steady. There is an input for inventory managers to compare if they are satisfied with profits gained from investing more resources to inventory budget and warehouse space.

4.4.2 Additional computation on optimal number of group

This section presents an optimal number of inventory group comparisons between the optimal ABC and the optimal inventory classification presented in Models 3.2 and 3.3, respectively. The computation was conducted to determine the optimal number of inventory groups when warehouse space is fixed and inventory budget is varied, and vice versa.

4.4.2.1 Fixed warehouse space and various inventory budgets

The optimal inventory group comparison is calculated on fixed warehouses space of 500 pallets and various inventory budgets from 90,000 USD to 160,000 USD with increments of 10,000 USD. The management overhead cost is 300 USD.

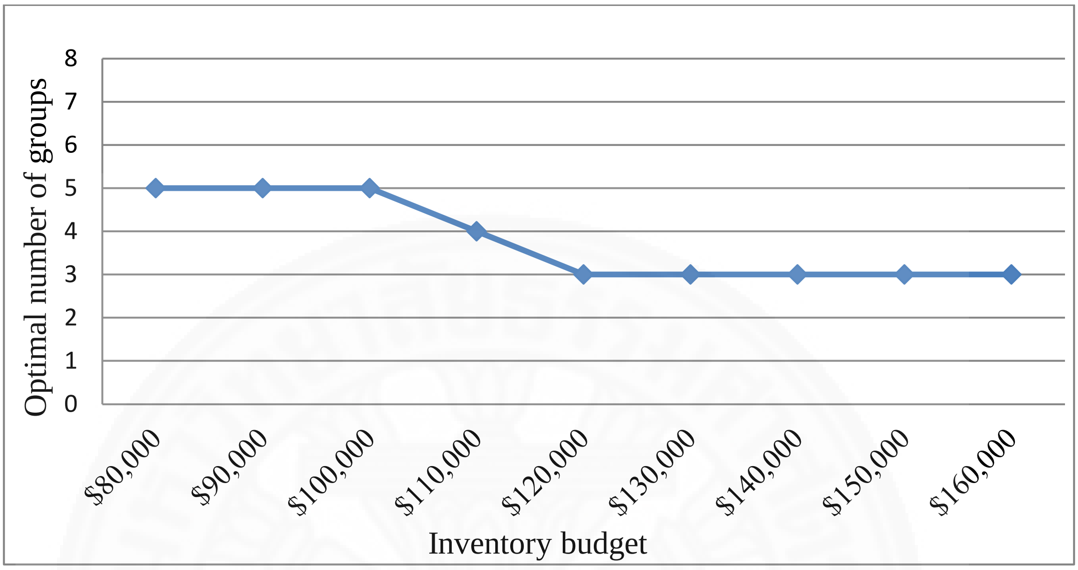

Figure 4.14 Optimal number of inventory group with fixed warehouse space and various inventory budgets

The line graph shows the optimal number of inventory groups found by the optimal inventory classification model when the inventory budget is varied with fixed warehouse space. The optimal number of inventory groups increases when we decrease the inventory budget. There is less incentive to assign more inventory groups when the inventory budget is huge.

4.4.2.2 Fixed inventory budget and various warehouse spaces

The inventory budget is fixed with 200,000 USD with various warehouse spaces from 430 pallets to 500 pallets with increments of 10 pallets space.

Figure 4.15 Optimal number of inventory groups with fixed inventory budgets and various warehouse spaces

This graph presents the optimal number of inventory group calculated by the optimal inventory classification model when the warehouse space is varied with a fixed inventory budget. The optimal number of inventory group increases when we decrease the warehouse space. There is an incentive to allocate the SKUs in more groups when there is small warehouse space. The inventory managers don't need to assign SKUs in many groups when the warehouse space is big.

Insight 3. It is optimal to select more inventory groups when warehouse space is tight and the inventory budget is huge; there is less incentive to have more inventory groups when there is tight inventory budget.

Insight 4. It is optimal to select more inventory groups when the inventory budget is tight and the warehouse space is huge; there is less incentive to have more inventory groups when there is ample inventory budget.

Chapter 5

Conclusion

5.1 Conclusion

In this study, two optimal inventory grouping models are proposed to improve inventory decision making within a limited inventory budget and warehouse space. The first model, the optimal ABC model is built to improve the existing traditional ABC model by choosing the optimal service levels for groups A, B, and C within a limited inventory budget and warehouse space. The second model, the optimal inventory classification model simultaneously examines the warehouse space, inventory budget, number of inventory groups, their corresponding service levels, and determines assignment of SKUs into groups. It develops the ABC inventory classification method by providing harmonious, computerized and optimized solutions. This study is different from the previous studies in the literature because of the consideration of inventory budget, warehouse space, and management overhead cost to maximize net profit by finding an optimal SKUs assignment and service level.

These two proposed models assist inventory managers to assign SKUs in warehouses more effectively. The first model helps inventory managers to choose the optimal service level when there are limited inventory budget and warehouse space, and the traditional ABC approach cannot be applied. The second model shows that when the warehouse space is decreased it is optimal to assign SKUs into more granular groups with different service levels. This study also provides several managerial insights. (i) By using the optimal ABC model, the net profit increases as the inventory budget and warehouse space increase. (ii) The profit earning by increasing value of inventory budget and warehouse space is not steady. (iii) It is optimal to select more inventory groups when warehouse space is tight and the inventory budget is huge; there is less incentive to have more inventory groups when there is tight inventory budget. (iv) It is optimal to select more inventory groups when the inventory budget is tight and the warehouse space is huge; there is less incentive to have more inventory groups when there is ample inventory budget.

When the inventory budget is tight, the optimal inventory has more than three groups.

5.2 Recommendation for further study

This work has been focused only on single criteria, so the future study could examine inventory classification optimization with multiple criteria. We are also looking to continue our research on perishable SKUs which have a shelf life and flexible management overhead cost which is a gap for future study.

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Appendices

Appendix A

Data Generation

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1																
2																
3			Ovcost	5000		MaxGroup	108		Overhcost	300						
4			Avabudge	100000		NofSKU	994		Avaspace	1000						
5																
6		NofSKU	Profit	Mdemand	Leadtime	Holdingcost	Annual D Usa	UnitCost	Ovcost	UnitsinPal	OrderCost	EOQ	Q/2	AvDeman	SdDemandL	
7		1	225.388	44	0.5	14.9270099	22.3905148	895.6206	300	25	500	54	27	22	1.76	2
8		2	266.2078	36	0.75	17.9879655	26.9819483	1079.278	300	61	500	45	22	27	2.16	3
9		3	240.526	38	0.75	16.741259	25.1118885	1004.476	300	15	500	48	24	28.5	3.135	3
10		4	218.7164	36	0.5	17.5920387	26.3880581	1055.522	300	13	500	45	23	18	1.62	2
11		5	285.177	34	0.75	18.1775618	27.2663427	1090.654	300	61	500	43	22	25.5	2.04	3
12		6	260.3579	34	0.5	18.0525885	27.0788827	1083.155	300	33	500	43	22	17	1.36	2
13		7	301.165	34	0.75	17.9457737	26.9186605	1076.746	300	57	500	44	22	25.5	2.04	3
14		8	291.2572	35	0.5	17.3880225	26.0820338	1043.281	300	40	500	45	22	17.5	1.75	2
15		9	244.2444	34	0.75	17.7497686	26.6246529	1064.986	300	56	500	44	22	25.5	2.295	3
16		10	271.274	33	0.75	18.2785017	27.4177526	1096.71	300	68	500	42	21	24.75	1.98	3
17		11	220.8097	36	0.5	16.6511785	24.9767678	999.0707	300	33	500	46	23	18	1.44	2
18		12	277.5767	38	0.75	15.7521541	23.6282311	945.1292	300	64	500	49	25	28.5	2.565	3
19		13	246.8621	33	0.5	17.7179022	26.5768532	1063.074	300	59	500	43	22	16.5	1.485	2
20		14	290.0685	36	0.5	16.2303283	24.3454924	973.8197	300	21	500	47	24	18	1.44	2
21		15	266.6865	37	0.75	15.7701346	23.6552019	946.2081	300	17	500	48	24	27.75	2.22	3
22		16	287.9486	34	0.75	17.059211	25.5888165	1023.553	300	54	500	45	22	25.5	2.295	3
23		17	250.6157	35	0.75	16.5710674	24.8566012	994.264	300	50	500	46	23	26.25	2.1	3
24		18	241.374	32	0.75	18.0848109	27.1272164	1085.089	300	47	500	42	21	24	2.4	3
25		19	284.628	34	0.75	16.9566688	25.4350032	1017.4	300	62	500	45	22	25.5	2.55	3
26		20	228.8107	37	0.75	15.4673147	23.200972	928.0389	300	51	500	49	24	27.75	2.775	3
27		21	245.2054	33	0.75	17.2942035	25.9413053	1037.652	300	10	500	44	22	24.75	1.98	3

+ NofSKU is number of SKUs = 1000 SKUs

+ Profit

Use uniform 10% to 30% of unit cost

Group A 20% to 30%

Group B 15% to 25%

Group C 10% to 20%

+ Mean of Monthly Demand

The first 20% (A Group) of 1000SKU uses normal distribution mean = 30, Standard Deviation = 5, then is rounded to be an integer

The Second 30% (B Group) of 1000SKU uses normal distribution mean = 15, Standard Deviation = 5, then is rounded to be an integer

The third 50% (C Group) of 1000SKU uses normal distribution mean = 10, Standard Deviation = 5, then is rounded to be an integer

+ Lead time

Use uniform range between 2 weeks to 3weeks

+Holding Cost

It is 20% of unit cost per year, so monthly divide by 12 (In theory, holding cost could from5% to 20% of unit cost per year. We chose 20% to make sure our model can deal with high holding cost to produce maximize profit)

+ Unit Cost

We use uniform range between 50 USD to 1100 USD.
Group A from 750 to 1100 (200 SKU)
Group B from 300 to 749 (300 SKU)
Group C from 50 to 299 (500 SKU)

+ Standard deviation of monthly demand

We use uniform to generate the date range between 7% to 10% for group A and B, respectively. For inventory group C standard deviation of mothy demand is range from 10% to 12%.

Appendix B

Input Testing

Input testing in section 4.2

Figure 4.1: Profit comparison between the traditional ABC and this optimal ABC (scenario 1)

Model	Profit (USD)
Traditional ABC	$1,641,071
Optimal ABC	$1,688,725

Figure 4.2: Profit comparison between the traditional ABC and this optimal ABC (scenario 2)

Model	Profit (USD)
Traditional ABC	$1,641,071
Optimal ABC	$1,843,463

Figure 4.3: Profit comparison between the optimal ABC with and without minimum service level requirement in group C

Optimal ABC	Profit (USD)
Optimal ABC(Scenario 3)	$1,584,417
Optimal ABC(Scenario 3) with minimum service level 10% in group C	$1,573,347

Figure 4.4: Profit comparison from a traditional ABC model and an optimal ABC model with different warehouse spaces

Fixed Inventory budget (USD)	140,000
Management Overhead Cost	$300

Warehouse Space (pallet)	ABC	ABC*

440	N/A	$1,774,170
460	N/A	$1,817,710
480	N/A	$1,839,488
500	$1,641,071	$1,845,461
520	$1,641,071	$1,845,950
540	$1,641,071	$1,845,950
560	$1,641,071	$1,845,950

Figure 4.5: Profit comparison from the traditional ABC model and the optimal ABC model with various inventory budgets.

Fixed Warehouse Space (pallet)	540
Management Overhead Cost	$300

Inventory Budget (USD)	ABC	ABC*
80,000	N/A	$810,664
90,000	N/A	$1,240,204
100,000	N/A	$1,572,448
110,000	$1,641,071	$1,788,251
120,000	$1,641,071	$1,817,710
130,000	$1,641,071	$1,845,950
140,000	$1,641,071	$1,845,950
150,000	$1,641,071	$1,845,950

Input testing in section 4.3

Figure 4.6: Profit comparison between the traditional ABC and the optimal inventory classification (Scenario 1)

Model	Profit (USD)
Traditional ABC	$1,641,071
Optimal classification	$1,703,899

Figure 4.7: Profit comparison between the traditional ABC and the optimal inventory classification (Scenario 2)

Model	Profit (USD)
Traditional ABC	$1,641,071

Optimal classification	$1,843,493

Figure 4.8: Profit comparison calculate by the traditional ABC model and the optimal inventory classification model with various warehouse spaces

Fixed Inventory budget (USD)	140,000
Management Overhead Cost	$300

Warehouse Space (pallet)	ABC	The optimal Inventory classification model
440	N/A	$1,817,168
460	N/A	$1,836,052
480	N/A	$1,846,798
500	$1,641,071	$1,852,786
520	$1,641,071	$1,855,146
540	$1,641,071	$1,855,456
560	$1,641,071	$1,855,456

Figure 4.9: Profit comparison by the traditional ABC model and the optimal inventory classification model with various inventory budgets.

Fixed Warehouse Space (pallet)	540
Management Overhead Cost	$300

Inventory Budget (USD)	ABC	The optimal Inventory classification model
80,000	N/A	$1,070,810
90,000	N/A	$1,370,099
100,000	N/A	$1,621,428
110,000	$1,641,071	$1,794,389
120,000	$1,641,071	$1,848,442
130,000	$1,641,071	$1,855,456
140,000	$1,641,071	$1,855,456
150,000	$1,641,071	$1,855,456

Input testing in 4.4

Figure 4.10: Profit comparison between the optimal ABC model and the optimal inventory classification model

Model	Profit
Optimal ABC	$1,774,171
Optimal classification	$1,817,488

Figure 4.11: Profit comparison calculated by the optimal inventory classification model and the optimal ABC model with various warehouse spaces

Fixed Inventory Budget	$120,000
Management Overhead Cost	$300

Warehouse Space(pallet)	The Optimal Classification model	The Optimal ABC model
340	$1,539,700	$1,231,725
360	$1,626,280	$1,309,343
380	$1,691,510	$1,433,765
400	$1,744,629	$1,608,355
420	$1,787,394	$1,718,567
440	$1,817,188	$1,774,170
460	$1,836,052	$1,817,710
480	$1,845,793	$1,838,588
500	$1,848,442	$1,840,545

Figure 4.12: Profit comparison by the optimal inventory classification model and the optimal ABC model with various inventory budgets.

Fixed Warehouse Space (pallet)	480
Management Overhead Cost	$300

Inventory Budget	The Optimal Classification model	The Optimal ABC model
$60,000	$206,154	$64,164
$70,000	$708,985	$465,661
$80,000	$1,070,810	$811,565
$90,000	$1,370,100	$1,241,104
$100,000	$1,621,458	$1,573,347
$110,000	$1,794,389	$1,789,151
$120,000	$1,845,793	$1,839,488
$130,000	$1,846,797	$1,839,488
$140,000	$1,846,797	$1,839,488

Figure 4.13: Profit comparison by the optimal inventory classification model with various inventory budgets and various warehouse spaces

Profit (USD)	Warehouse Space (Pallet)							
Inventory Budget	360	380	400	420	440	460	480	500
$70,000	$708,966	$708,932	$708,985	$708,958	$708,985	$708,985	$708,985	$708,985
$80,000	$1,070,743	$1,070,743	$1,070,814	$1,070,739	$1,070,757	$1,070,757	$1,070,810	$1,070,757
$90,000	$1,370,094	$1,370,094	$1,370,093	$1,370,093	$1,370,093	$1,370,093	$1,370,100	$1,370,093
$100,000	$1,593,683	$1,616,258	$1,621,437	$1,621,429	$1,621,392	$1,621,429	$1,621,458	$1,621,429
$110,000	$1,626,280	$1,691,409	$1,744,619	$1,779,532	$1,792,603	$1,794,452	$1,794,389	$1,794,331
$120,000	$1,626,280	$1,691,510	$1,744,629	$1,787,394	$1,817,188	$1,836,052	$1,845,793	$1,848,442
$130,000	$1,626,280	$1,691,526	$1,744,710	$1,787,319	$1,817,138	$1,836,175	$1,846,797	$1,852,774
$140,000	$1,626,280	$1,691,527	$1,744,710	$1,787,319	$1,817,138	$1,836,175	$1,846,797	$1,852,774

Figure 4.14: Optimal number of inventory group with fixed warehouse space and various inventory budgets

Fixed Warehouse Space (pallet)	500
Management Overhead Cost	$300

Inventory Budget (USD)	Number of Group
$80,000	6
$90,000	5
$100,000	5
$110,000	4
$120,000	3
$130,000	3
$140,000	3
$150,000	3
$160,000	3

Figure 4.15: Optimal number of inventory groups with fixed inventory budget and various warehouse spaces

Fixed Inventory Budget	$200,000
Management Overhead Cost	$300

Warehouse Space(pallet)	Number of Group
420	7
430	7
440	5
450	5
460	5
470	5

480	5
490	4
500	3

Appendix C

International Conference

Flexible ABC inventory classification

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Abstract

ABC inventory classification is a well-known approach to assign inventory item into A, B, and C groups based on their sales and usage volume. This helps inventory management become more efficient. Behind its advantage, it usually shows some problems with an inventory budget and warehouse space because the ABC assignment of SKUs are made without an inventory budget and space available involved. In this paper, the ABC group under restricted of an inventory budget and warehouse space to maximize the profit with optimal service level is presented. We establish this proposed model to enhance the existing ABC approach to be more applicable in real life, which has the limited inventory budget and warehouse space.

Keywords: *ABC inventory classification, Inventory Management.*

1. INTRODUCTION

Agro-industry products need a very careful inventory management to maintain quality of the products. ABC inventory classification is a well-known approach to assign inventory items into A, B, and C groups. Each group has an individual policy to manage products appropriately. This classification uses the Pareto principle. The traditional ABC approach is simple to understand and is used by inventory managers and supervisors. SKUs are classified based on their annual use values and sales.

A small number of items may contribute to the large proportion of volume, while a medium group may have a moderate proportion of volume. A large number of items may account for a small proportion of volume (Pareto and Page 1971). This often shows that a small proportion of the SKUs accounted for the majority of company's sales and revenue. This has led to the 80-20 rule. The top 20% of inventory is grouped as the A class and the next 30% and 50% are grouped as class B and class C, respectively (Flores and Clay Whybark 1986). Each class already has a selected service level. For example, 95%, 75%, and 50% are set for class A, B, and C, respectively. Implementers usually use the traditional ABC grouping scheme in following approach to manage inventory. First, SKUs are classified based on their sale volume. Second, inventory policies are decided for each group. Finally, the inventory manager needs to verify with financial department to ensure that inventory policy is feasible within the provided inventory budget and available warehouse space. There are some disadvantages of ABC inventory classification. (a) There are no clear approaches to determine the service level in the literature Teunter et al. (2010). (b) Since the inventory grouping decision is made separately from the available budget and warehouse space, there is no guarantee that set service level is feasible.

The study presented in this paper improves the ABC inventory classification to be more flexible. First, SKUs are grouped by annual use value the same as ABC approach. Then, the model simultaneously chooses the optimal service level for each group within available inventory budget and warehouse space. These inputs are made to maximize the total revenue. We use generated data to implement in traditional ABC and this proposed model. We compare the solution from this model and traditional ABC model on total 1,000 SKUs.

This paper is organized as follows. Section 2 provides the related research literature and emphasizes contribution on this work. Section 3 discusses our proposed model. Section 4 the computational result is presented. Finally, Section 5 summarizes and concludes this work.

2. LITERATURE REVIEW

There are many research studies focus on inventory classification exist in the literature. However, most of them are conducted to extend from single criteria to multi-criteria classification by using difference model and approach. There are no existed studies has conducted to find the optimal service level on traditional ABC. Some of them focus only on inventory grouping alone, while other researchers have included inventory control such as policy and performance.

The classic method of making group as ABC based on a volume/cost metric (Pareto & Page, 1971) have been used to extend by many researchers to consider multi criterions. The first multi-criteria classification using the joint criteria matrix was conducted by considering lead times, substitutability, critical factors, commonality and reparability (Flores and Clay Whybark 1986). Partovi and Burton (1993) used the analytic hierarchy process to propose a systematic approach to quantify the priority of SKUs.

Some researchers treated inventory classification as an optimization problem. They use a weight linear program based on Data Envelopment Analysis (DEA) Ramanathan (2006) and Zhou and Fan (2007), and extended by Hadi-Vencheh (2010) and Chen (2011). Guvenir and Erel (1998) developed the genetic algorithm with metaheuristic. The other metaheuristic called particle swarm optimization has been developed by Tsai and Yeh (2008).

The other type of inventory classification addressed the relationship between classification and control decisions. Those studies were conducted to minimize the total inventory cost calculated by the summation of holding cost and ordering cost. Crouch and Oglesby (1978) conducted the research to minimize the total inventory cost. In their model, the holding cost of all SKUs was assumed the same over the time period. However, it seems difficult to apply in real life. The study of minimizing the cost by considering the product of demand rate and holding cost rate (or PHDC) was researched by Chakravarty (1981). That research used their dynamic programming algorithm which was improved by PDHC to illustrate that the optimal grouping can be obtained.

Millstein, Yang, and Li (2014) recently developed an optimization model to find the optimal number of inventory group and service level for each group under considering the available inventory budget and management overhead cost. The overhead cost of their study was set to be constant. The objective function is set to maximize net profit. They assigned SKUs in more than three groups with specified service level (fill rate) for each group to maximize the total profit. It still has problem to apply in real life because the thousands of SKUs need to be reassigned again which led to many unexpected problems and more expenses. This study is conducted to maximize profit which focuses on single criteria. The inventory budget and warehouse space is simultaneously included in this model which is different from all literature studies.

3. MODEL DEVELOPMENT

This study still uses the approach of ABC inventory classification based on annual use value. After that, the target service level for each group will be assigned by our model written in CPLEX. The optimized service level which considered together with inventory budget and warehouse space is built to maximize the profit. It has been formulated as mixed integer linear program (MILP).

Notation.

-NA, NB, & NC: Number of inventory items in group A, B, & C (SKUs)

-MA, MB, & MC: maximum number of inventory group A, B, & C

-d_{ia} , d_{ib}, & d_{ic} : mean of monthly demand of SKU ia, ib, & ic =1,…,NA, NB , & NC

- σ_{ia} , σ_{ib} , & σ_{ic} : standard deviation of monthly demand of SKU ia, ib, & ic=1,…,NA ,NB, & NC

- l_{ia}, l_{ib} & l_{ic} lead time of SKU ia, ib, & ic =1,…,NA, NB, & NC

- g_{ia}, g_{ib}, & g_{ic} : net profit per unit of SKU ia, ib, & ic = 1,…,NA, NB, & NC

- c_{ia}, c_{ib}, & c_{ic} : inventory holding cost per unit SKU ia, ib, & ic=1,…,NA, NB, & NC

- z_{ja}, z_{jb}, & z_{jc} : z-value associated with group ja, jb, & jc=1,…,MA,MB, &MC

- s_{ja} , s_{jb}, & s_{jc} : service level associated with group ja, jb, & jc:1,…,MA, MB, & MC

- B: planned inventory spending budget

- IP_{ia}, IP_{ib}, & IP_{ic} : maximum number of item i can store with 1 pallet ia, ib, & ic= 1,…,NA, NB, &NC

- ATS: Total number of pallet can store in provided space

Decision variable

yA_{ja}, yB_{jb}, & yC_{jc} =1 if inventory group ja, jb, and jc is selected, and 0 otherwise. for ja, jb, & jc=1,…,MA, MB, & MC

xA_{iaja}, xB_{ibjb}, & xC_{icjc}= 1: if SKU ia, ib, and ic is assigned to group ja, jb, and jc for ia, ib, & ic =1,…,NA, NB, & NC; and ja, jb, & jc=1,…,MA, MB, &, MC

v_{ia}, v_{ib}, & $v_{ic} \geq 0$: inventory level of SKU ia, ib, & ic= 1,…,NA, NB, & NC

Objective function

Maximize

$$\sum_{ia=1}^{NA}\sum_{ja=1}^{MA} g_{ia}d_{ia}s_{ja}xA_{iaja} + \sum_{ib=1}^{NB}\sum_{jb=1}^{MB} g_{ib}d_{ib}s_{jb}xB_{ibjb} + \sum_{ic=1}^{NC}\sum_{jc=1}^{MC} g_{ic}d_{ic}s_{jc}xC_{icjc} \quad (1)$$

Constraints

$$\sum_{ja=1}^{MA} xA_{iaja} = 1, \quad \forall ia=1,..,NA \quad (2)$$

$$\sum_{jb=1}^{MB} xB_{ibjb} = 1, \quad \forall ib=1,..,NB \quad (3)$$

$$\sum_{jc=1}^{MC} xC_{icjc} = 1, \quad \forall ic=1,..,NC \quad (4)$$

$$\sum_{ia=1}^{NA} xA_{iaja} = NAy_{ja}, \forall ja=1,…,MA \quad (5)$$

$$\sum_{ib=1}^{NB} xB_{ibjb} = NBy_{jb}, \forall jb=1,…,MB \quad (6)$$

$$\sum_{ic=1}^{NC} xC_{icjc} = NCy_{jc}, \forall jc=1,…,MC \quad (7)$$

$$v_{ia} = \sum_{ja=1}^{MA} d_{ia}l_{ia}xA_{iaja} + \sum_{ja=1}^{MA} z_{ja}\sigma_{ia}\sqrt{l_{ia}x_{iaja}}, \forall ia=1,..,NA \quad (8)$$

$$v_{ib} = \sum_{jb=1}^{MB} d_{ib}l_{ib}xB_{ibjb} + \sum_{jb=1}^{MB} z_{jb}\sigma_{ib}\sqrt{l_{ib}x_{ibjb}}, \forall ib=1,..,NB \quad (9)$$

$$v_{ic} = \sum_{jc=1}^{MC} d_{ic}l_{ic}xC_{icjc} + \sum_{jc=1}^{MC} z_{jc}\sigma_{ic}\sqrt{l_{ic}x_{icjc}}, \forall ic=1,..,NC \quad (10)$$

$$\sum_{ia=1}^{NA} c_{ia}v_{ia} + \sum_{ib=1}^{NB} c_{ib}v_{ib} + \sum_{ic=1}^{NC} c_{ic}v_{ic} \leq B \quad (11)$$

$$\sum_{ia=1}^{NA}\frac{v_{ia}}{IP_{ia}} + \sum_{ib=1}^{NB}\frac{v_{ib}}{IP_{ib}} + \sum_{ic=1}^{NC}\frac{v_{ic}}{IP_{ic}} \leq ATS \quad (12)$$

$$v_{ia} \geq 0, \quad \forall ia=1,..,NA \quad (13)$$

$$v_{ib} \geq 0, \quad \forall ib=1,..,NB \quad (14)$$

$$v_{ic} \geq 0, \quad \forall ic=1,..,NC \quad (15)$$

xA_{iaja} = [0,1], ∀ia=1,..,NA ; ∀ja=1,…,MA

xB_{ibjb} = [0,1], ∀ib=1,..,NB ; ∀jb=1,…,MB

xC_{icjc} = [0,1], ∀ic=1,..,NC ; ∀jc=1,…,MC

(16), (17), & (18)

yA_{ja}, yB_{jb}, and yC_{jc} = [0,1], ∀ja=1,…,MA ; ∀jb=1,…,MB, ∀jc=1,…,MC (19), (20), & (21)

The objective function (1) is built to maximize the total profit, calculated by the summation of the gross profit generated by groups A, B, and C. The service level (s_{ja} , s_{jb}, and s_{jc}) is treated as a fill rate to calculate the satisfied demand by inventory level. The fill rate has also been used by other researchers such as Teunter et al. (2010) and Millstein et al. (2014). Constraints (2), (3), and (4) force the model to assign an SKU into one group. Constraints (5), (6), and (7) enforce that only an open group is allowed to be assigned an SKU. Constraints (8), (9), and (10) calculate the inventory level of SKUs by the summation of demand during the lead time and safety stock (in the case of uncertain demand and certain lead time) (Ballou 2007). Constraint (11) ensures that the inventory budget is higher than the total inventory holding cost. Constraint (12) ensures that the total space required to store all SKUs do not exceed the available warehouse space. Constraints (13) through (21) identify the domains of decision variables.

4. COMPUTATIONAL RESULT

In the calculations, the potential 108 different service levels from 1% to 99% (with the increment of 1%), include 9 service levels from 99.1% to 99.9% (with the increment of 0.1%), which are chosen to consider for ABC service levels. We solved our MILP model by the branch and cut method in CPLEX 12.3 on a laptop PC with 2.7 GHz CPU speed and 8 GB memory. CPLEX spent about 1 minute and a half to find the optimal solution (and prove optimality).

We implement the model in three scenarios. *Scenario 1:* we set the inventory budget 104,000 USD and warehouse space 500 pallets. *Scenario 2*: the inventory budget and warehouse is set higher with 118,000 USD and 520 pallets space to see how our model flexibly assigns the service level. *Scenario 3*: the proposed model uses within the tight inventory budget 100,000 USD and warehouse space of 430 pallets. We set these three scenarios to see how flexible this model is in different situations.

We compare traditional ABC classification (with 95%, 75%, and 50% for service level of group A, B, and C, respectively) with the proposed optimal ABC classification (ABC*). Results are following

In Scenario 1, by changing the traditional ABC service level to optimal service level, which found by the proposed MILP model, its profit improves 2.9% from 1,641,071 USD to 1,688,725 USD. The service for ABC group is changed from 95%, 75%, & 50% to the optimal service level 92%, 89%, & 82%, respectively. Profit found by our model and ABC traditional is shown in Table below.

In Scenario 2, inventory budget and warehouse space increase. The model improves profit up to 12.33% compared to the traditional ABC by changing the service level to 99.3%, 99.1%, and 99% for group A, B, and C, respectively. Though we increase the inventory budget and space, the ABC method still keeps the same service level which provides no profit improvement. However, this model finds optimal service level to maximize profit.

The ABC approach will be infeasible if the inventory budget and warehouse space are lower than numbers provided in Scenario 1. In Scenario 3, we decreased inventory budget to 100,000 and 430 pallet space available to see how flexible our model is. The profit found by changing the service level to 89%, 85%, & 1% of ABC group is 1,584,417 USD. The model assigned group C to have only 1% of service level. It seems inapplicable in real life; however, to maximize the profit within a limited budget and warehouse space, it is an optimal solution.

Table: Profit in USD comparison between the traditional ABC and the optimal ABC in three scenarios

	Scenario1	Scenario2	Scenario3
ABC	1,641,071	1,641,071	infeasible
ABC*	1,688,725	1,843,463	1,584,417

We perform the additional experiment by control the service level of group C to have more than 10% of service level on our proposed model. The reason for controlling the service level is to show that our model is capable of altering condition, based on the changing of inventory policy. The result shows that the proposed model is flexible in real life with inventory policy in different situations. The net profit provides by the proposed model is 1,573,348 USD by changing the service level 86%, 83%, and 69% for group A, B, and C, respectively. It is slightly smaller than the previous experiment by only 0.69%. This proposed model produce more benefit when there are more inventory budget and bigger warehouse space while the traditional ABC cannot improve profit. There is no guarantee that traditional ABC is feasible with rule 95%, 75%, and 50% of service level when we have tight inventory spending budget and limited warehouse space. This model can decide service level for each group flexibly to maximize profit base on available inventory budget and warehouse space. Moreover, instead of allowing the program chooses the service level freely, we can control the range of service level that we want. It is suitable for inventory manager to plan the inventory policy in the diverse market situation.

CONCLUSIONS

In this study, we have developed an optimization model to improve a well-known ABC inventory classification approach by choosing an optimal service level for each group. There are two different things that make our model differs from the existing optimization model in the literature. First, our objective function is set to maximize profit which, to our knowledge, there was only one study conducted to maximize profit, while other studies focus on minimize total cost. Second, our solution provides the optimal service level within a limited inventory budget and warehouse space which is an important input for inventory managers. Our solution also helps inventory managers to choose the optimal service level when there are limited inventory budget and warehouse space, while the ABC approach cannot apply. The future study could focus on multiple criterions. We are also looking for possible to continue our research on perishable SKUs which has a shelf life and flexible overhead management cost which is a gap for future studies.

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