An Integrated Network Design and Inventory Optimization Model For a Perishable Supply Chain Toward Sustainable Development

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Abstract

For many items, decisions related to supply chain management have not been an easy task. It is then much more complex for perishable items than the other. Besides cost-efficiency, other factors, such as customer expectation and product freshness, have significant contributions to competitive advantages and business's reputation. In other words, it would be flawed to care about either cost or profit ignoring other objectives. A multi-objective model for such items is, thus necessary. In this regard, this study introduces an integrated network design and inventory optimization model considering a perishable supply chain from a sustainable perspective. The mathematical model is to maximize profit, minimize the freshness loss of products at the point of demand fulfillment, and minimize the solid waste stress of the supply chain. In the result analysis, a numerical case is used to demonstrate the model utilization and the decision-making process. Max-Min Operator is to solve a multi-objective model. The model resulting shows tradeoffs among the objectives. Additionally, decision-makers can observe influences of the environment and society along with the economy on supply chain-related decisions, and vice versa.

Keywords
Inventory optimization, Multi-objective Optimization, Network Design, Perishable Items, Solid waste.

1. Introduction
Supply chain management for perishable items such as foods and biological-based products is the topic that has received research attention recently, especially in the context of inventory management. During the past few years, inventory optimization has been one of the important tools allowing decision makers to achieve economic inventory management plans while being able to pursue service-level and other management objectives. When considering customers as the main stakeholder, the incorporation of customer satisfaction in inventory planning can be regarded as the attempt to strengthen supply chain's social sustainability performance. To contribute to this interesting research field, this study develops a multi-objectives inventory optimization model for perishable products. The development of an inventory plan for perishable products is a complex task as the plan needs to account for not only the shelf life but also the demand-fulfillment ability of the remaining products and spoilage. On the other hand, finding suitable inventory planning is always a great opportunity to improve the profit and reduce loss. In this study, we present the case where customers perceive the positive social impacts of inventory control that maximize the freshness of products at the point of their demand fulfillment. The proposed model helps decision-makers determine optimal order quantity and order frequency in terms of costs and freshness level consideration.

Additionally, the model simultaneously takes into account network design problem. Traditionally, this problem is to identify the location to build facilities and warehouses in order to maximize the overall performance of the supply chain. Companies nowadays start thinking about the interaction between network design and other decisions, especially the inventory planning. When and how much products are placed to store in the warehouses in conjunction with how to design the distribution networks to optimize the profit and customer satisfaction. At the same time, decisions should benefit to environmental and social responsibilities of the network. As mentioned before, the proposed model considers multi-objectives relating to the sustainability goals. If the inventory optimization problem concerns about profit and the product's freshness loss respectively standing for economic and social aspects, the network design corporates the environmental issues, namely the solid waste stress (SWS). The SWS relates to accumulated solid waste of potential locations where are planned to build the distribution point. The model is then to display and discuss about how the SWS affects the network design as well as the inventory-related decisions. On vice versa, influences of the integrated network design and inventory optimization model on the three pillars of sustainability.

There are two main problems included in the proposed model, namely inventory optimization and network design problem. The highlights of inventory optimization are 1) the ability to track the remaining shelf-life of products and the demand fulfillment by products with different freshness levels; 2) the use of a freshness-based social impact indicator in optimization. On the other hand, the network design problem looks at 3) the impacts of supply chain network design on the sustainability goals; and 4) the integration of solid waste generation into the network design and inventory optimization problems. The problem, model formulation, and analysis details are provided in the subsequent parts of the study.

2. Literature Review

Inventory optimization of perishable products
Inventory-related decisions play crucial role in perishable product supply chain management. An inventory optimization model (IOM) is generally to determine inventory levels, optimal order quantity, and order frequency. Having said that a well-managed inventory system can help a company save operational costs (Sebatjane and Adetunji 2020). However, the IOM is practically complicated and challenged because of the product's characteristics, particularly the product's shelf life and freshness level.

The effects of changes in the products' lifetime or freshness on supply chain performance have been investigated by recent researches. Chen, Chen et al. (2019) propose an approach capable of determining the optimal replenishment and pricing policies for short-life products with a random lifetime due to deterioration. They introduce a case where the deterioration rate is a function of the inventory level. While, Wei, Liu et al. (2020) consider a perishable product at retailer where the time-varying freshness function is used. They apply GA in order to determine the optimal pricing and replenishment policy under the profit maximization. Following that, Shirzadi, Ghezavati et al. (2021) solve the inventory routing problem where the quality decay of products and its consequence on customer's dissatisfaction cost examined. Sebatjane and Adetunji (2020); Shen, Li et al. (2020) present inventory management models, capable of handling freshness- and price-dependent demand, for a perishable product supply chain. The mentioned studies mostly aim to provide optimal inventory plans on the way to achieve the cost-effectiveness goal. This may result in losing a customer who expects to use green and fresh products. Therefore, environmental or social aspects should be taken into account. The question is how to provide "green" and "fresh" products in the context of inventory optimization.

It is well noted that effects of product deterioration on cost are commonly investigated in most cases of inventory planning. Besides, carbon emission is another interesting aspect of the effects explored in following studies. Yavari and Zaker (2019) develop a network design approach for the perishable products supply chain. The cost and carbon emission impacts associated with the changes in the products' lifetime under the disruption condition are evaluated. Yu, Qu et al. (2020) take into account the carbon emission due to the storage of perishable products over their lifetime in their inventory management approach. Furthermore, environmental protection is also considered based on the buyer's perspective. Shi, Zhang et al. (2020) suggest a model integrating payment schemes and inventory decisions for the perishable product. The work considers and analyzes effect of degrading rate of the product and payment methods on the replenishment policy as well as the climate change.

There are a few limited studies that actually embed product freshness or consumer's freshness perception within supply chain optimization objectives, particularly to explore the social sustainability design. These studies recognize consumers as the primary stakeholder and aim to strengthen the underdeveloped social sustainability pillar. In this regard, Yakavenka, Mallidis et al. (2020) develop a network design model incorporating product freshness into their social responsibilities. Their goal-programming model ensures the fresh deliveries of food products through the selection of transportation modes, facility location selection, and product flow determination. Liu, Zhu et al. (2021) develop a sustainable supply chain management model that simultaneously considers cost, carbon emissions, and freshness of perishable products. Jouzdani and Govindan (2021) demonstrate the use of their sustainable food supply chain network design approach that comprehensively consider the three pillars of sustainability. However, the social impact considered is related to the traffic congestion caused by the network design, not the freshness of products. The study proposed by Jouzdani and Govindan (2021) investigates a multi-objective optimization model for inventory and production management of a supplier, manufacturer, and retailer under the sustainable context. The product's freshness is controlled by applying a first-in-first-out policy. Nevertheless, the sustainable aspects are considered by the supplier and manufacturer.

Consequently, the interaction between product freshness and social sustainability into inventory optimization is truly necessary. Therefore, this study develops an inventory optimization model that focuses on tracking and maximizing the freshness levels and the amount of the perishable inventory that fulfills demand. The freshness satisfaction objective is formulated in terms of freshness loss minimization. The traditional cost and profit consideration is also made. Additionally, the model takes into account penalty cost which the distributor must pay for expired-products (waste). It implies that the distributor takes responsibility for environmental pollution problems.

The network design for perishable product supply chain

The development of globalization of production and trade have simultaneously created opportunities and challenges for supply chain management, especially for perishable items. In order to meet the increasing of customer demand, companies need to make appropriate decisions regarding the supply chain network, such as product flow, transportation mode, facility location. Because of special condition requirements in production and delivery, perishable supply chain network design (PSCND) has become a challenging task. There are thus a range of studies, including both single-objective and multi-objectives models, have been done over years. Traditional PSCND models mostly focus on economic effective. For instance, Tsao (2016), De Keizer, Akkerman et al. (2017), and Dagne, Jayaprakash et al. (2020) develop single objective models maximizing total profit of multi-echelon SC under the quality deterioration rate of the product. In addition, the time-related factor is considered in the last two studies. If Tsao (2016) addresses the replenishment cycle time, the order of transportation time is taken into account in the study of Dagne, Jayaprakash et al. (2020).

Besides economic performance, the environmental and social issues significantly influence the supply chain decisions, and vice versa. Bi-objective or multi-objective models, regarding environment and society, have been increasingly proposed. In which, environmental aspects are especially concerned in the field of PSCND. Musavi and Bozorgi-Amiri (2017) propose a case study of a food supply chain with an aim at minimizing total costs and CO2 emission of hub network simultaneously. The authors also address the freshness and quality of food via delivery time. On the other hand, Kaboli Chalmardi and Camacho-Vallejo (2019) introduce PSCND model which is to encourage the use of cleaner technologies. The purpose is to minimize environmental impacts and supply chain costs. Furthermore, the study of Wang, Nhieu et al. (2021) suggest a multi-objective model to design the configuration of four-echelon supply chain. The authors try to balance among objectives, including costs, delivery time, transportation emission, and the supply-demand mismatch in time. It can be seen that researchers and practitioners have significantly contributed to achieving emission reductions with a slight increase in total costs by configuring supply chain.

Besides efforts in reducing emissions from transportation among facilities, there is a need to look at the solid waste generation (SWG) which is one of the top concerns for city authorities. A vast of studies, which is to provide efficient solutions in dealing with solid waste management, has been published over years. Studies of Inghels, Dullaert et al. (2016), Xu, Elomri et al. (2017), Olapiriyakul, Pannakkong et al. (2019), etc. focus on designing waste management network design which tend to sustainable development. These proposed studies not only consider cost minimization, they put huge efforts in reducing carbon emissions and social impacts of SWG. However, this study is to integrate the SWG into perishable product supply chain as an environmental metric.

Hence, this study proposes an integrated network design and inventory optimization model for a case of perishable supply chain. We develop a multi-objective model, which takes into account three fundamental sustainability dimensions: economic, environmental, and social aspects. As mentioned before, there are three objectives, namely profit maximization, freshness loss minimization, and solid waste stress minimization. The purpose is to display and discuss about tradeoffs among objectives. Consequently, decision-makers are able to observe the influence of aspects on supply chain related decisions, especially network design and inventory decisions, and vice versa.

3. Problem description

Aforementioned, the study proposes an integrated network design and inventory optimization model considering the product's freshness in the context of sustainability. There are two main decisions made in the model, namely 1) the configuration of the supply chain; 2) the inventory planning of distributors. As the increasing of customer demand, the company plans to open new distributors, which will serve a group of customers within a specific area. Besides, the company desires to select suppliers providing products to opened distributors with an aim at ensuring the quality and the freshness of the product. Usually, fresh product is shorter shelf life, faster turns and lower inventory levels than the other. Hence, delivering and storing these products are touch and complex. The question is how to combine the configuring the supply chain network and determining inventory planning in the way to optimize an overall performance.

The current study considers 3 potential suppliers and 10 potential locations to open distributors. According to the company's target and capacity, they decide to open four new distributors with an aim to maximize total profit while taking the environmental responsibility by considering the solid waste generation. The decision-maker simultaneously proposes an inventory planning determining optimal order quantity, and order frequency for opened distributors providing three types of products over 24 periods. An efficient planning helps the company gain a high profit and an acceptable freshness loss level at the end of the planning horizon. Specifically, the proposed model includes three objective functions, namely profit maximization (TP), freshness loss minimization (TFL), and solid waste stress minimization (SWSM) which stand for the three pillars of sustainability.

The profit objective relates to the revenue getting from selling products to the customer; and total costs including replenishment cost, inventory cost, disposal cost, and construction cost. The replenishment cost includes product and ordering costs, which depend on the ordering lot size. There are three ordering size, namely small (1500), medium (2500), and large (3500). The model assumes that there is no difference about the two costs among suppliers. Besides, the inventory and disposal costs depend on product type and fluctuate over time. While the construction cost directly relates to location's conditions.

On the other hand, the second objective, freshness loss minimization relates to the length of time that the product is stored in the warehouse. It means that the longer time the product is stored in the warehouse, the more its freshness reduces. When the freshness level is zero (or the percentage of freshness loss is 100%) meaning that the product cannot be sold and the distributor must pay disposal cost for it. The objective directly affects the customer satisfaction, which stands for the social aspects considered in the model.

While the environmental aspect is linked to the 3rd objective, solid waste stress minimization. The objective considers the accumulated solid waste of locations (provinces) which is selected to build distributors. To estimate the solid waste stress (SWS) of province, we need to collect the accumulated solid waste of each province (ASW) and the average level of accumulated solid waste of provinces (Ave-ASW). The SWS is a ratio between ASW and Ave-ASW. Minimizing SWS means the supply chain has a tendency to build distributor at province where the SWS is low.

In fact, the company cannot achieve optimal value of objectives at the same time. Therefore, this study suggests the multi-objective optimization (MO) known as an effective tool to handle multiple objectives and to gain the set of feasible solutions showing the tradeoff between objectives. It is then solved by using Max-Min Operator method.

4. Mathematical model

Model assumption

This study considers the inventory optimization problem for one product over 24 periods (T). The mathematical model is developed based on the following assumptions:

- Each distributor will provide three types of products to fulfill the customer demand at the province where the distributor is opened.
- All customer demands in the province where the distribution point is opened must be fulfilled
- There is no initial inventory
- The distributor cannot place more than one order per period
- The distributor receives the product at the end of the ordering period
- The customer demand is satisfied at the end of the period
- The remaining inventory is computed at the end of each period

- The expired product (remaining life is zero) becomes waste and cannot be used for demand fulfillment

A. Notation

Parameters

De_{ip}^{t}	The customer demand of product p at province i at period t
Stc_i	The storage capacity of the distributor located at province i at period t
Sc_j	The supply capacity of the supplier j
Dw_p	The disposal weight per unit of the product p
SP_{ip}^{t}	The price per unit of the product p sold at province i at each period t
PC_{jipl}^{t}	The product replenishment cost (per unit) of product p that the supplier j sells to province i at period t, lot size l
IC_p^t	The inventory cost per unit of the product p at period t
OC_{jipl}	The ordering cost of product p corresponding to ordering lot size l for the order placed by the distributor i from supplier j
DC_{pi}	The disposal cost of product p at province i when the shelf life of the product equals 0
FC_i	The construction cost occurring when the distributor is opened at province i
OS_{jpl}	The number of products p corresponding to the ordering lot size l which is defined by supplier j
FL_{ps}^{t}	The percentage of the freshness lost at different remaining shelf-life s and period t of product p
s_i	The waste sensitivity index of each province
$BigM$	A huge number
N	The number of opened distributors

Decision variables

OA_{jipl}^{t}	The number of products type p in the order that the distributor i places from the supplier j at period t
YO_{jipl}^{t}	$\begin{cases} 1 & \text{, if the company palce an order of level l at period t} \\ 0 & \text{, otherwise} \end{cases}$
Y_{ji}	$\begin{cases} 1 & \text{, the supplier j provides product to distributor i} \\ 0 & \text{, otherwise} \end{cases}$
IA_{ips}^{t}	The number of products type p in the inventory with the remaining shelf-life s at province i and period t
X_{ips}^{t}	$\begin{cases} 1 & \text{, the availability of the inventory of product p at province i in a specific shelf life s} \\ 0 & \text{, otherwise} \end{cases}$
Pr_{ips}^{t}	The percentage of the customer demand fulfilled by the product p with remaining shelf-life s at province i and period t
W_i	The total weight of expired products generated at province i over planning horizon
YD_i	$\begin{cases} 1 & \text{, the distributor is opened at province i} \\ 0 & \text{, otherwise} \end{cases}$
UM_{ip}^{t}	The number of unmet units of product p at province I at each period. This occurs at province where the distributor is not opened

B. Objective functions

The model includes three objective functions, which are profit maximization, freshness loss minimization, and solid waste stress minimization shown in equation (1), (2), and (3) respectively.

The first objective (OF1)

$$OF1=\sum_{i\in I}\sum_{p\in P}\sum_{t\in T}SP_{ip}^{t} * De_{ip}^{t} * YD_i - \sum_{j\in J}\sum_{i\in I}\sum_{p\in P}\sum_{l\in L}\sum_{t\in T}PC_{jipl}^{t} * OA_{jipl}^{t} - \sum_{j\in J}\sum_{i\in I}\sum_{p\in P}\sum_{l\in L}\sum_{t\in T}OC_{jipl} * YO_{jipl}^{t} - \sum_{i\in I}\sum_{p\in P}\sum_{s\in S}\sum_{t\in T}IC_{p}^{t} * IA_{ips}^{t}$$
$$-\sum_{i\in I}\sum_{p\in P}\sum_{t\in T}DC_{ip} * Dw_p * IA_{ip(s=0)}^{t} - \sum_{i\in I}FC_i * YD_i \quad (1)$$

The second objective (OF2)

$$\text{OF2} = \sum_{i\in I}\sum_{p\in P}\sum_{s\in S}\sum_{t\in T}FL_{ps}^{t} * IA_{ips}^{t} \quad (2)$$

The third objective (OF3)

$$\text{OF3}= \sum_{i\in I}s_i * W_i * YD_i \quad (3)$$

C. Constraints

The proposed model is satisfied following constraints from (4) to (29). Basically, the model is subjected by the customer demand, supply capacity, storage capacity, and the product's shelf life

$$\sum_{j\in J}\sum_{l\in L}OA_{jipl}^{t} = De_{ip}^{t} * YD_i + \sum_{s\in S}IA_{ips}^{t} \qquad ,\forall i,p,\ t=1 \quad (4)$$

$$\sum_{j\in J}\sum_{l\in L}OA_{jipl}^{t} + \sum_{s>0}^{S}IA_{ips}^{(t-1)} = De_{ip}^{t} * YD_i + \sum_{s\in S}IA_{ips}^{t} \qquad ,\forall i,p,\forall t: t>1 \quad (5)$$

$$\sum_{j\in J}\sum_{p\in p}\sum_{l\in L}\sum_{t\in T}OA_{jipl}^{t} = 0 \qquad ,if\ YD_i = 0,\ \forall i \quad (6)$$

$$De_{ip}^{t} = UM_{ip}^{t} \qquad ,if\ YD_i = 0,\ \forall i,\forall p,\forall t \quad (7)$$

$$UM_{ip}^{t} = 0 \qquad ,if\ YD_i = 1,\ \forall i,\forall p,\forall t \quad (8)$$

$$\sum_{i\in I}\sum_{l\in L}OA_{jipl}^{t} \le SCap_{jp} \qquad ,\forall j,\forall p,\forall t \quad (9)$$

$$OA_{jipl}^{t} \le YO_{jipl}^{t} * BigM \qquad ,\forall j,\forall i,\forall p,\forall l,\forall t \quad (10)$$

$$OA_{jipl}^{t} = OS_{jpl} * YO_{jipl}^{t} \qquad ,\forall j,\forall i,\forall p,\forall l,\forall t \quad (11)$$

$$\sum_{j\in J}\sum_{l\in L}YO_{jipl}^{t} \le 1 \qquad ,\forall i,\forall p,\forall t \quad (12)$$

$$\sum_{i\in I}YD_i = N \quad (13)$$

$$\sum_{j\in J}Y_{ji} \le 1 \qquad ,\forall i \quad (14)$$

$$\sum_{p\in P}\sum_{l\in L}\sum_{t\in T}YO_{jipl}^{t} \le Y_{ji} * BigM \qquad ,\forall j,\forall i \quad (15)$$

$$\sum_{j\in J}Y_{ji} \le YD_i \qquad ,\forall i \quad (16)$$

$$IA_{ips}^{t} = IA_{ip(s+1)}^{(t-1)} - De_{ip}^{t} * Pr_{ips}^{t} \qquad ,\forall i,\forall p,\forall s: s\le 2,\forall t: t>1 \quad (17)$$

$$IA_{ips}^{t} = \sum_{j \forall J} \sum_{l \in L} OA_{jipl}^{t} - De_{ip}^{t} * Pr_{ips}^{t} \qquad , \forall i, \forall p, s > 2, \forall t \qquad (18)$$

$$IA_{ips}^{t} = 0 \qquad , \forall p, \forall i, t = 1, s \leq 2 \qquad (19)$$

$$\sum_{s=1}^{S} \Pr_{ips}^{t} = 1 * YD_{i} \qquad , \forall p, \forall i, \forall t \qquad (20)$$

$$\Pr_{ip(s=0)}^{t} = 0 \qquad , \forall p, \forall i, \forall t \qquad (21)$$

$$IA_{ips}^{t} \leq X_{ips}^{t} * BigM \qquad , \forall p, \forall i, \forall t \qquad (22)$$

$$IA_{ips}^{t} \geq X_{ips}^{t} \qquad , \forall p, \forall i, \forall t \qquad (23)$$

$$Pr_{ips}^{t} \leq 1 - \sum_{s>1}^{S} X_{ip(s-1)}^{t} \qquad , \forall p, \forall i, \forall t \qquad (24)$$

$$\sum_{p \in P} \sum_{s=1}^{S} IA_{ips}^{t} \leq StCap_{it} \qquad , \forall i, \forall t \qquad (25)$$

$$W_{i} = \sum_{p \in P} \sum_{t \in T} Dw_{i} * IA_{ip(s=0)}^{t} \qquad , \forall i \qquad (26)$$

$$OA_{jipl}^{t}, IA_{ips}^{t}, UM_{ip}^{t} \geq 0, \text{ Integer} \qquad (27)$$

$$Pr_{ips}^{t} \geq 0 \qquad (28)$$

$$YO_{jipl}^{t}, X_{ips}^{t}, YD_{i}, YS_{ji} \text{ are binary variables} \qquad (29)$$

Equations (4) and (5) ensure the balancing between customer demand, ordering amount, and inventory amount. Equations (6) – (8) show that if the distributor is not opened at province i, then there is no ordering amount from suppliers to this distributor. Equations (9) ensures that the total ordering amount from opened distributors cannot exceed the supply capacity of each supplier. Equation (10) shows the ordering amount from supplier j to province i. Equation (11) and (12) are about the lot size order constraints. Equation (13) sets up the number of distributors that the company expects to open. Equations from (14) to (16) indicate that the distributor only places products from one supplier over planning horizon. Equation (17) and (18) allow the model to track the remaining inventory amount at specific remaining shelf life. Equation (19) shows that there is no initial inventory. Equations (20) and (21) restrict the value of Pr_{ips}. Equations (22) to (24) force the distributor use the older inventory to meet the demand (first in first out rule). Equation (25) relates to the storage capacity of the distributor. Equation (26) computes total disposal weight over periods. Equations (27) to (29) are about non-negative, integer, and binary constraints.

5. Results and Discussion

As mentioned before, the proposed model tends to show tradeoffs among three objectives. In order to observe and analyze these tradeoffs, the study displays solutions gained from both single-objective and multi-objective models. In this regard, there are four solutions called S1, S2, S3, and S4 standing for OF1, OF2, OF3, and the multi-objective model (MO), respectively.

5.1 Economic consideration (revenue and costs)

Figure 1 shows that there are four opened distributors located at province 1, 2, 5, and 9. They receive products from suppliers to fulfilled their customer demand so that the total obtained profit is maximum, approximately 1,148,689 baht. Each distributor will receive all types of products from only one supplier which is the most closed to the distributor. This result is appreciated and fit to the real-world situation.

Figure 1. The solution of OF1

5.2 Environmental consideration (disposal waste and solid waste stress)

If the 1st objective allows the company get the high performance in term of economic aspect, the 2nd objective concerns the customer satisfaction which is one of the core indicators representing for the social aspects. In this regard, the customer satisfaction is measured via the freshness loss ratio (FL) of products. There are two dimensions changing the FL, namely (1) inventory level and (2) the length of time that the product stored in the warehouse. First, the inventory level directly relates to the number of inventories over periods. The more the inventories are stored, the more the FL increases. Thus, one of the effective suggestions is to minimize total inventory amount at each period.

Figure 2. The solution of OF2

Figure 2 shows that there are four opened distributors located at province 1, 2, 5, and 9, similar to S1. However, these distributors receive products from supplier 1 only to fulfilled their customer demand. Then, the total freshness loss is about 16,232.9 while the total profit is at 939,381.68 baht. Additionally, the solid waste stress gained from S2 is about 569.22.

5.3 Social consideration (freshness level and customer satisfaction)

As shown in Figure 3, the supply chain network includes 4 distributors opened, namely DC4, DC5, DC8, DC9. In which, supplier 1 provides products to DC4, DC5, and DC9 while the supplier 3 only serves DC8. The question is why DC8 buys products from supplier 3 which is far away from it. This happens because the current objective (solid waste stress minimization) ignores the travel cost between supplier and distributor. In this case, the model focuses location where the distributor is opened in order to minimize the SWS. Consequently, the total s SWS is about 87, which nearly equals to 15% of SWS produced from the 2nd objective, and 3.4% from the 1st objective. Therefore, the proposed network assists the company in taking the environmental responsibility effectively

Figure 3. The solution of OF3

5.4 The tradeoffs among objectives

Figure 4 displays the comparison about profit, freshness loss, and solid waste stress among three objectives. Arrows is used to show how objectives change when using Max-Min Operator. For instance, Figure 4a indicates that the profit achieved from the MO decreases in comparison to OF1. It also means that the total profit of MO is lower than the one of OF1. The explanation is similar to Figure 4b and 4c. The decision-maker is able to observe the figure to see the tradeoffs among objectives clearly, and then make an appropriate decision.

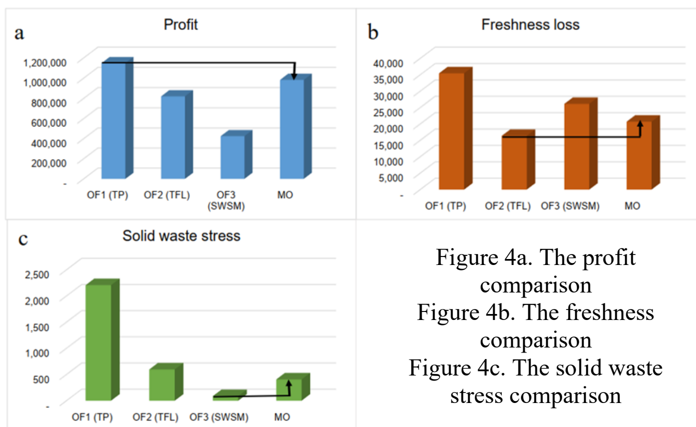

Figure 4a. The profit comparison
Figure 4b. The freshness comparison
Figure 4c. The solid waste stress comparison

Figure 4. The comparison among objectives

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