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# Combing TOC and the replenishment model for optimizing deteriorating inventory management: A case study of the aerospace industry

# 結合限制理論與補貨模型進行退化性存貨之最佳化：以航空製造業公司為例

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**Abstract:** As there are strong and positive correlations between the reliability of aircrafts and passenger safety, the requirement on quality and choices of materials and components remains a top priority compared to all other industries. Some aircraft materials, such as paint, glue, rubber, and composites, deteriorate in quality and value over time, resulting in stock shortages. In addition, high inventory levels of materials are the main characteristic of the aircraft manufacturing industry due to design change requests and the variety and complexity of the materials. This study adopts a two-stage process to improve inventory management for the case company in the aerospace industry. The first stage systematically assesses issues such as bargaining power and determines the relevance and interactive influence among sectors related to inventory management. By using the theory of constraints (TOC), this study further diagnoses the undesirable effects (UDEs) of material management systems and identifies root problems or inconsistent material management actions. Via UDEs, the second stage constructs a current reality tree (CRT) to realize a company's

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material management objectives and requirements and to figure out what actions it must take to meet these objectives. This study also explores four scenarios that would benefit from such improvement. The ultimate goal in the future is for vendors to be able to distribute profits according to the corresponding situation.

**Keywords:** Aerospace manufacturing industry, theory of constraints, material management, simulation analysis.

**摘要：**航空器可靠度與乘客安全有強烈的關聯，故在材料、零組件的要求標準皆高於其他產業。航空器的部分材料如漆、膠料等，其材料強度與價值隨時間遞減，加上不同航空器材料零件的特殊性，致使生產過程的缺料問題。但如為了避免缺料而過量存貨，遇到航空器構型變更，材料報廢將影響專案績效表現。本研究以兩階段存貨管理模型改善個案航空製造公司的存貨問題。先系統性地個案公司生產製造全貌，例如在航空製造業的議價能力、與生產製造相關的內部部門存貨管理制度。藉由限制理論方法，本研究診斷出個案公司物料管理的不良效應 (undesirable effects, UDEs) 根本原來自於內部各部門的物料管理方針不一所致。第二階段透過現況樹 (current reality tree, CRT) 了解個案公司物料管理全貌，並邀請外部夥伴及內部各部門協調，避免強調部門績效反而降低整體專案獲利的現象。透過四種生產模型的模擬分析結果，個案公司得在不同議價能力與價格基礎下，達到最佳化專案績效目標。

**關鍵詞：**航空製造、限制理論、物料管理、模擬分析．

## 1. Introduction

Because the operating environment of the aircraft industry is highly strict and closely bound with human lives and safety, the requirement on quality and choices of materials and components remains a top priority for aircraft manufacturing compared to other industries. The main goals of this industry are to maintain stable delivery routines, cost control, and finished (semi-finished) products. For an original design manufacturer (ODM) contract, the aircraft manufacturer must pay more attention to delivery schedule, costs, and product quality in order to ensure its profitability.

The inventory operation management literature focuses mainly on forecasting supply and demand in order to reduce inventory fluctuations, such as material shortages. The value and quality of inventories typically change over time and may cause volatility, deterioration, or decay during the process of maintenance. Many companies lower their deteriorating inventories by manipulating their delivery schedule, which further results in material shortages or de-committed deliveries thus negatively impacting profits (Ferguson and Ketzenberg, 2006).

Deteriorating inventory in the aerosace industry includes products such as paint, glue, rubber, and composite materials. Finding the best order quantity to reduce waste thus has been the ultimate goal in many research studies (Avinadav *et al.*, 2013). The specific characteristics of the aircraft manufacturing industry, including schedule changing, unstable engineering project, and complexity of materials, are all reasons that prompt manufacturers to hold materials in order to respond to any unexpected changes. In addition, the aerospace industry is constrained by the special properties of aerospace materials, and so the costs of purchasing components and inventories remain very high.

To achieve a balance between cost (profit) and customer satisfaction, the world's major aircraft manufacturers apply several additional strategies, such as joint procurement collaboration with other aircraft makers and flexible contracts to spread the total risk and cut costs. By integrating the procurement process, better cooperation arises between manufacturing and sales and among suppliers and customer, setting up a win-win situation for all involved.

There are many ways to look at inventory management in the aircraft manufacturing industry. At the enterprise level, there are different indices for inventory management performance among different sectors. The procurement model is based on a pattern of less quantity and more batches, which enhance the turnover rate. However, this may result in possible material shortages to the production side and thus higher costs. The quantity per order and firm size are two main factors that affect a supplier's priority of delivery. Smaller aircraft manufacturers are therefore constrained by limited bargaining ability and can only acquire good supply through joint procurement or excess procurement.

Some previous studies do not provide enough systematic thinking when exploring inventory management within a certain sector and when trying to improve inventory management (Gao, 2015). In the aircraft manufacturing industry, all raw material procurements and storages are carried out in projects, but many times customer have to change the project contract in the middle of the manufacturing process. Therefore, when the external environment results in the customer making a project update or Engineering Change Notice (ECN), it leads to greater fluctuation in material needs, which may influence the original project and increase demand uncertainty.

The inventory ordered for a project deteriorates along with time, because it has to be consumed within a regulated period. However, in order to not pause production, the sector often prevents material shortages through overbooking. Accordingly, when the project is over, the remaining deteriorated inventory must go through a “re-test” or “quality test for extending product usage” to make sure the product can still be made available for use. However, whether the inventory is unexpired at the warehouse or the inventory is expired yet still available after a re-test, it can only be used under customer approval. Customers require an extra test of this type of deteriorating inventory to ensure the quality of material. Using non-planned deteriorating inventory provides cost effectiveness to both the customer and aircraft manufacturing companies.

A company will also consult with upstream suppliers to make an acquisition of these deteriorating inventories under discounted prices. If the customer accepts the existing inventory, then the old inventory will be used as soon as possible. If the supplier is willing to make an acquisition of the excess products for other uses, then the company will be able to clear the inventory and reduce its inventory cost.

The economic value of deteriorating inventory declines faster than ordinary inventory. Through the application of management tools, the operation performance of an aircraft manufacturing company can be improved. For inventory management, this paper is different from previous studies. First, through a systematic diagnosis, we look to understand the strategic goals among each related sector in an aircraft manufacturing company to find out the relevance among inventory targets and whether they influence each other. After clarifying the inventory issues, through a mathematical model in operations research we calculate inventory management according to different situations.

This study adopts two stages to improve inventory management for the case company. The case company is an international aircraft manufacturing company in Taiwan with 3,000 workers. Its paid-in capital is NT$9 billion, and its earnings before profit and taxes (EBIT) are NT$1.3 billion. The case company's core business currently focuses on OEM and ODM aircraft manufacturing.

The first stage systematically assesses issues such as bargaining power as an external manner for inventory agenda, which may be encountered by every sector, and further seeks the relevance and interactive influence among sectors related to inventory management. According to the results diagnosed in this stage, the second stage investigates solutions through the mathematical model. Our model uses interactive influences among sectors with different goals for inventory management and investigates the most important variable that affects policy on deteriorating inventory and optimizes it. This study also explores four scenarios for benefit improvement. In the future, vendors should practically be able to distribute profits according to the corresponding situation.

This paper is organized as follows. Section 2 reviews the important literature about deteriorating inventory and systematic diagnostic tools. Section 3 introduces the research method and research steps used herein. Section 4 illustrates the diagnosis and analysis results of this study. Managerial implications and future research suggestion are in section 5.

# 2. Literature review

## 2.1 The inventory issue for deterioration products

This problem specifically refers to the changing processes of products or materials such as damage, decomposition, evaporation, obsolescence, and expiration that cause initial quality or economic benefits to decrease. In particular, the change that occurs through time in a non-linear fashion is called deterioration (Wang *et al*., 2012; Wee, 1992).

Deteriorative inventory can be divided into two types. The first type is perishable inventory, where as time goes by, the product quality gradually declines. An expiration date indicates when the product value or function is exhausted. A ubiquitous example would be fresh food. The second type is gradually perishable inventory, where quality gradually declines over time. A common example would be a rubber tire.

Nahmias (1982), Silver (1979), and Weatherford and Bodily (1992) have made major contributions to studies on deteriorative products. They also profoundly influenced future scholars' investigations of various issues that may impact management of deteriorative products such as different pricing models, maintenance costs, and fixed and uncertain expiration dates (Chun, 2003; Herbon *et al.*, 2012). Deteriorative inventory not only affects a company's inventory maintenance costs, but it may also lead to possible shortage risks during the production process. Therefore, many scholars view product deterioration as a key factor in the inventory management model and adhere to it when conducting optimal calculations (Battini *et al.*, 2010; Lee and Dye, 2012; Mahata, 2012; Persona *et al.*, 2005; Wang *et al.*, 2012).

Ghare and Schrader (1963) were the first to include characteristics of inventory deterioration into inventory-related studies. They also made the assumption that inventory quality gradually decreases in a linear way. Nahmias (1978), however, divided inventory economic value into two types: regular and irregular periods of inventory retention.

Maihami and Kamalabadi (2012) and You (2005) established the inventory management model for deteriorative materials by combining linear price and exponential time functions. They explored inventory management with high market sensitivity to determine how to optimize production batch numbers as well as order volume when facing high volatility in market demand in order to maximize corporate profits.

Operations management studies on aircraft manufacturing have also begun to include the idea that inventory can deteriorate and have a shelf life (Chiu, 1995; Frangopol and Maute, 2003; Hadley and Whitin, 1961). A return policy is one source of a manufacturer's competitive advantages. Particularly in cases involving seasonal and deteriorative commodities, returns are costly to the manufacturer (Toktay, 2003). Thus, stipulating product return and exchange policies for firms has always been a significant challenge in logistics management (Chen and Bell, 2012; Gecker and Vigoroso, 2006).

Hahn *et al*. (2004) further explored deteriorative inventory from a supply chain perspective. Analyzing the two circumstances of first in/first out and last in/first out, they utilized a buyout-styled optimal price discount model adopted for deteriorative products. Lau and Lau (1999), Marvel and Peck (1995), and Stock *et al*. (2002) looked at return policies for deteriorative products from the manufacturer perspective., Choi *et al*. (2004), Emmons and Gilbert (1998), Hahn *et al*. (2004), and Pasternack (1985) investigated such issues from the cooperative perspective between manufacturers and retailers. Kandel (1996), Mantrala and Raman (1999), and Padmanabhan and Png (1997) added the game theory perspective to their study and examined a return policy-influenced inventory model under different bargaining powers of various manufacturers in a supply chain.

If upstream suppliers or manufacturers can provide sound product return policies, then this may strengthen cooperation as well as profitability for various supply chain manufacturers (Davis *et al*., 1995; Loss Prevention Research Council, 2008; Xiao *et al*., 2010). When external factors such as demand changes cause original product or materials to no longer satisfy initial customer demand, then manufacturers may peddle, repurpose, or return their inventories to suppliers in order to lower financial costs. For suppliers, introducing a return policy may increase operating costs and risks. Thus, under a procuring contract that allows returns, despite higher purchasing fees to the manufacturer, overall cost can still decrease while at the same time boosting competitive advantages.

## 2.2 Theory of constraints (TOC)

Within the domain of operations management, Material Requirements Planning (MRP), Supply Chain Management (SCM), Just-in-Time (JIT), and Enterprise Resource Planning (ERP) are among the most widely-used tools. The Theory of Constraints (TOC) is a relatively new and lesser known operations management tool. It was created by Israeli physicist Eliyahu M. Goldratt in the 1980s.

The philosophy behind TOC is that an organization consists of a series of rings, and thus the strength of an organization (performance) is determined not by the strongest ring, but instead by the weakest. If one aims to increase overall organizational performance, then work should begin on the weakest ring in order to achieve success. TOC consists of three major segments: A series of systematic thinking, five focused assessment steps for improvement, and the constant cycling of five focused improvement processes (Boulding *et al.*, 2005; Schragenheim and Dettmer 2001).

- Each system has its own objective as well as a series of specific actions intended to achieve it.
- The overall performance of a system is greater than the combined performance of each individual subsystem.
- There are a few factors or restrictions present at any time (usually just one) interfering with overall system performance.

The strength of the entire system is determined by the weakest ring. Therefore, the weakest ring is the output restriction of the whole system (Goldratt and Weiss, 2005; Gupta and Snyder, 2009). Goldratt (1990) proposed five TOC-based steps to solve existing constraints present within a system. Through these steps, managers can concentrate resources and energy on the restriction-related rings and subsequently elevate the entire system's performance.

The advantages of TOC also strengthen its applications on operations-related research as well as practice, such as improvement in in-transit inventory, lead time, instant delivery, inventory turnover, product quality auditing, profitability, etc. Rahman (2002) used TOC to diagnose the systematic relevance between inventory management and cost. Umble and Murakamis (2006) utilized TOC to examine conflicts and improvements among tool machinery production activities. Reviewing case studies conducted with TOC, more than half (42/81) have demonstrated that TOC can actually improve inventory costs and overall manufacturing time, whereas 75% of the companies showed over 40% improvement in terms of costs, further proving that TOC indeed possesses value in practical diagnosis and improvement.

In today's increasingly complex world, the nature of the subjects also influences inventory management. Thus, the application of TOC has also been extended from single firms to entire supply chain systems (Tsou, 2013). The present inventory management model is also more diverse. For example, the ERP system either transfers inventory management over to suppliers or reduces inventory to increase firm operational flexibility (Simatupang *et al.*, 2004; Tsou, 2013).

**Table 1**
**Five focused steps for improvement and their corresponding meaning for management**

| Focused steps of TOC | Managerial implications |
|---|---|
| 1. Find the systematic constraint: count the numbers of activities and find the ones with performances lower than their targets. | The restriction of a system may come from the inside (due to organizational resources, ability, or strategy) or outside (economic cycle, customer preferences).<br>It is essential to clearly comprehend the source of the restriction and ask: What resources does the system have to enhance the degree of goal achievement? |
| 2. Use restriction: Maximize the efficiency of the activities that created the restriction. | Remove all waste or unproductive time and activity. |
| 3. Adjust the other activities: Based on the above approach, find the other bottlenecks in the system. | Apply new methods to manage resources that are not used efficiently. |
| 4. Relax the restriction on the system: Improve the performance that causes any restriction on the system and make it no longer a bottleneck. | Apply additional resources to improve the performance of such bottlenecks. |
| 5. Go back to step 1 and avoid inertness: Review every activity of change to meet the current goal of the entire system. | Avoiding inertness means looking at the new system type and make sure introducing these changes are useful for opening up system bottlenecks. |

This study uses three TOC questions and five logical thinking processes. First, the research conducts an overall inspection using CRT to explain the undesired effects resulting from individual inventory management-related activities in case study companies. Second, the study clarifies the case company's inventory management goals using information acquired from meetings with experts as well as company managers. Third and finally, the study employs TOC to improve activity design and diagnosis as well as attempts to evaluate performance through the use of mathematical tools.

# 3. Research methods

## 3.1 Research methods

When a product's actual sales do not meet the initial threshold by retailers, they must then seek financial aid or credit from the manufacturer. A return policy comprises one possible risk whereby the manufacturer buys back a retailer's unsold stock. The main purpose of a return policy is to shift the holding and handling costs of goods in stock to the manufacturer. This encourages the retailer to store a massive amount of stock, reducing the likelihood of product shortages as well as increasing competitive advantages (Padmanabhan and Png, 1995). Therefore, a return policy encourages retailers to increase order quantities. A large order may reduce annual order processing costs to the merchant each year and may also reduce manufacturers' production costs. In this research the replenishment model mainly focuses on perishable products. Perishable products used in the aerospace industry are raw chemical materials used in airplanes or raw materials used in compound manufacturing.

To achieve the intended research purpose, this study adopts the following research methods.

(1) In-depth interview: The author invited sixteen experts from related sectors to understand the current case company's situation and solutions or projects currently implemented to improve inventory performance. Interviewees included four senior system management engineers, two purchase managers, five materials management engineers, one head materials management manager, and four production management engineers. The direction and goals for improvement will be mapped out based on the above experts' advice.

(2) Theory of Constraints: Based on the three questions and five steps proposed from TOC, the internal and external situations of the case company are analyzed, in order to discover the causes of issues that arise among sectors. Moreover, the research diagnoses existing conflicts among inventory policies in every sector and proposes suggestions for improvement.

(3) Mathematical programming: Based on the constraints proposed by the theory of improvement proposals, this study examines the impacts from

parameter changes through mathematical planning tools and sensitivity analysis.

## 3.2 Assumption

We provide the following assumptions to construct a heuristic model.

- Inventory levels are reviewed continuously. An order size Q, Q > 0, is placed when the inventory level reaches the reorder point R.
- All ordered units arrive fresh. It is assumed that each unit has a fixed lifetime m, and no loss or decrease in utility occurs before m time units.
- If each unit has not been used to meet a demand before the expiration date, then it must be discarded, and an outdate cost equal to w per unit is charged.
- The demand in unit time, du, is a non-negative random variable. Assume it follows a specific continuous or discrete distribution with density or mass function fx(dx) and mean D. It is also assumed that if N(t) is cumulative demand by time t, then {N(t), t>0} is a stochastic process with stationary, independent increments.
- There is a positive order lead time L for replenishment; L is less than the lifetime m.
- No overshoot occurs at the reorder point r.
- Units are always depleted according to a first in/first out (FIFO) policy.
- All excess or unsatisfied demand is backlogged.

## 3.3 Model parameters

| | |
|---|---|
| D | Average demand quantity per unit time |
| R | Reorder point |
| T | Lifetime of perishable items |
| L | Order lead time, L < T |
| c | Replenishment cost per unit |
| h | Holding cost per unit per unit time |
| p | Shortage cost per unit |
| w | Scrap cost per unit |
| k | Fixed ordering cost per order |
| OH | Expected inventory level |
| EAC | Average cost per period |

ES Expect shortage quantity per period (period is the time frame between each order)
ER Current estimated expired quantity within the order quantity
ET Time between orders

# 4. Analysis result

## 4.1 Current status of the case company

The case company is an aircraft manufacturing company, dealing primarily with aircraft ODM orders. Company forecasts are made based on customer forecasts that serve as a benchmark. When the Project Division receives orders from customers, it transfers the information (including quantity and delivery schedule) to the Sector of Material Control of the Material Division.

There is always the likelihood of incorrect estimates or order modifications from customers, which may further exacerbate wrong estimates or material demand forecasts. This could result in overbooking and subsequent chaos to the production schedule, in which both increase inventory management costs. While each individual sector attempts to enhance performance through various production tools, the phenomenon of “enhanced performance but decreased project profits” will arise.

After clarifying current issues and every corresponding management improvement strategy, the study further utilizes the thinking process developed by TOC to diagnose whether there are any correlations or conflicts in the firm’s current management improvement policy. A systematic diagnosis helps us to explore not only performances, but also conflicts among sectors. We then propose a systematic improvement method (Figure 1).

Through TOC and a diagnosis of the case company’s issues, we see that constraints from the policies made by suppliers, customers, and order changes have significant impacts on its inventory management performance. For practical considerations, the study proposes four scenarios and an optimized analysis accordingly.

***Scenario 1***: Under the case company’s current situation, inventory needs to be scrapped should there be anything left unused at the time the order expires. The

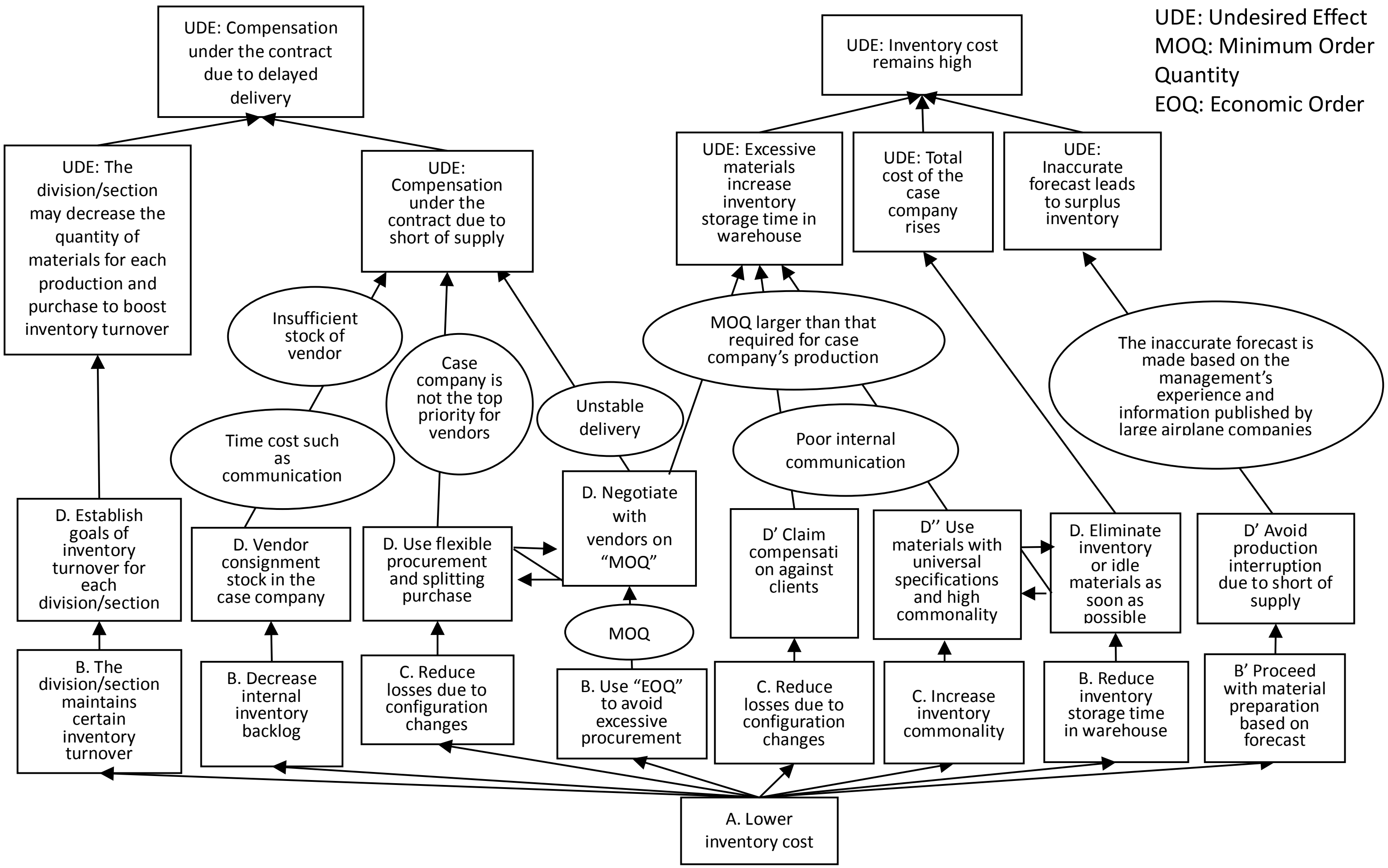


**Figure 1**
**Conflict resolution diagram and current reality tree of the case company A**

mathematical model is as follows:

$$\begin{aligned}\mathrm{EAC(Q,r)} &= \{\text{purchase order cost} + \text{pruduct cost} + \text{shortage cost} \\ &\quad + \text{scrap cost})/\ \text{time between orders}\} + \text{holding cost} \\ &= \{(\mathrm{k\times Q + c\times Q + p\times ES + w\times ER})/\mathrm{ET}\} + \mathrm{h\times OH} \qquad (1)\end{aligned}$$

$$\begin{aligned}\text{Scrap cost} &= \mathrm{w \times ER} \\ &= \mathrm{w}\begin{bmatrix}\int_0^{r+Q}(r+Q-d_{T+L})f_{T+L}(d_{T+L})\mathrm{d}d_{T+L} - \\ \int_0^{r}(r-d_{T+L})f_{T+L}(d_{T+L})\mathrm{d}d_{T+L} - \end{bmatrix} \qquad (2)\end{aligned}$$

Where $0 > \gamma > d_{T+L}$

$$\text{Time between orders(ET)} = (\mathrm{Q - ER})/\ \mathrm{D} \qquad (3)$$

$$\begin{aligned}\text{Holding cost} &= \mathrm{h\times OH} \\ &= \mathrm{h}(\mathrm{r - D\times L} + \tfrac{1}{2}Q) \qquad (4)\end{aligned}$$

The following is the base model of our research:

$$\begin{aligned}&EAC(Q,r) = \{(k\times Q + c\times Q + p\times ES + w\times ER)/ET\} + h\times OH\} \\ &= \left\{\begin{aligned}&k\times Q + c\times Q + p\int_r^{\infty}(d_L - r)f_L(d_L)\mathrm{d}d_L \\ &+w\begin{bmatrix}\int_0^{r+Q}(r+Q-d_{T+L})f_{T+L}(d_{T+L})\mathrm{d}d_{T+L} \\ -\int_0^{r}(r-d_{T+L})f_{T+L}(d_{T+L})\mathrm{d}d_{T+L}\end{bmatrix}\end{aligned}\right\}/ET + h(r - D\times L + \frac{1}{2}Q) \qquad (5)\end{aligned}$$

***Scenario 2***: Negotiate with suppliers to have surplus inventory purchased back.

Since the supplier is willing to buy surplus inventory back after project completion, the purchase price will be higher. Assuming the value "increased" is a certain proportion of the original product cost, the new product cost will be c(1+a). Price b for buying back the product is also a certain proportion of said product cost. Therefore, the price of buying back is $c\times b$. Moreover, the quantity purchased back by the supplier should be abandoned in "scenario 1". The relation between c (1 + a) and $cb$ affects order quantity Q and the relationship between order quantity Q and reorder point r in the original “scenario 1” in order to form a new order quantity $Q'$ and reorder point $r'$. The cost function of the case company is:

$$EAC(Q', r') = \{[k \times Q' + c(1+a) \times Q' + p \times ES - cb \times ER] / ET\} + h \times OH \quad (6)$$

Since b and v are a percentage of original product cost, this study expresses the amount refunded as $c \times b$, whereas the residual value is expressed as $c \times v$. In addition, as the quantity returned is the quantity scrapped, $Q - d_{T+L}$ in the Pastemack model is the ER value in the model modified from the quantity returned in this study. The above illustration helps meet the profit model of the supplier in this study shown below:

$$\text{profit model of supplier(S)} = \text{ca} \times \text{Q}' - ER(cb - cv) \quad (7)$$

***Scenario 3***: Negotiate with the customer

The case company negotiates to let customers use paint materials that have not expired or have expired yet remain available after extensive testing from previous projects. A discount is given in a proportion (e) as indicated in the project contract signed with customer. The old quantity (X) used by the new project will not be more than ER in the previous term, and therefore the quantity of scrapped inventory is $ER - X$, whereas the purchased quantity in every term is $Q''$, as $Q'' + X$ is the actual input quantity. The cost function of the case company is:

$$\begin{aligned} EAC(Q''\ r'') = {} & \{[k \times Q'' + c \times Q'' + p \times ES + w \times (ER - X)] / ET\} + h \times OH \\ & + X \times c \times e \end{aligned} \quad (8)$$

Here, $0 > \text{X} > \text{ER}$.

To the customers, the ratio of deteriorative inventory used by them is (1-X) with the discounted amount as $c \times e$. However, a change in quality likely occur dues to using such inventory. Thus, there is a risk for a higherreject ratio. The production yield rate from using deteriorative inventory is (1-$\alpha$). The profit formula for the customer is thus:

$$\text{Extra profit for customer } G = X(c \times e)(1-\alpha) \tag{9}$$

***Scenario 4***: Negotiate with either the supplier or customer

When the case company negotiates with the customer and supplier separately, this means the customer can use the existing product during the project, whereas the supplier will buy back unconsumed amounts when the project ends. The cost function is:

$$EAC(Q''', r''') = \{[k \times Q''' + c(1+a) \times Q''' + p \times ES - cb \times (ER - X)] \ / \ ET\} + h \times OH + X \times c \times e \tag{10}$$

## 4.2 Simulation analysis

This section introduces the basic assumption of our inventory model. Through the characteristics of deteriorating inventory and model assumption, we construct the basic model for the status without any need to negotiate between supplier or customer. As to data setting, this study denotes the degree of purchase cost increase as 0~2%. The amount of raw material returned is set to be 0 to 75% of the original purchased price; the percentage of discount for a customer is 0 to 100%; and the percentage of excess raw material used by the customer is 0.01 to 0.1.

***Scenario 1*****:** Primary inventory model (current status of the case company).

Based on the characteristic of gum paint and the hypothesis of the model, we construct a basic model that does not require a negotiation between the supplier and the customer. The basic assumption is that the perishable good has a shelf life of T, after which, if there is any unused gum paint, then a scrap cost of W will occur. The inventory goal of this study is to minimize total costs. The five detailed costs among total cost include product cost, inventory cost, cost from a lack of goods, order cost, and cost from discarded goods. Thus, the simulation results of the primary inventory model are expected average cost (EAC): 27810.72; order quantity (Q): 3.9; re-order point (r): 0.1; shortage quantity (ES): 3.9; scrap quantity (ER): 0.06; time between orders (ET): 0.96.

***Scenario 2***: Negotiate with the supplier to buy back surplus inventory

The result is the current status of the case company. All the inventory will be abandoned after the project is over. Based on the simulation result, when the original purchased price is unchanged, due to cooperative negotiation, the supplier is willing to refund the whole amount based on the residual value of raw materials. The cost to the case company may still reduce the unit price by $749.05.

Considering the risks, when the supplier increases the original purchased price by 1%, the supplier will buy back the remaining material at a price 53% higher than its residual value after the project is over. The benefits to both sides still increase. When the original purchased price is 2% higher, the buyback price rises by 56%.

As the supplier has fixed the price of buying the material back in the early stage of cooperation, we compare changes in cost under different purchasing prices for the case company. When the supplier only helps to take back the raw materials with no amount refunded and the case company can accept a premium price of 1%, the overall profit can achieve Pareto improvement by adjusting the purchase order. When the purchased price rises by 3% and the supplier is willing to refund 50% of the original price, the cost to the case company drops 58.87% and the profit for the supplier increases by 836.32%.

***Scenario 3*:** Negotiate with customer

Among all materials in the new project, X% of them are materials that already exist in other projects. Based on the extreme requirement of safety in the aviation industry, the reject rate $\alpha$ of existing products that the customer uses is estimated to be 0. Compared to the original purchase mode, the analytical result shows that all purchase combinations can achieve Pareto improvement, whereby the company's cost drops by 118.71% and the customer's profit increases by 0.55%. In this scenario, the profit the vendor achieves by changing the purchase model is far higher than the profit the customer gets. Therefore, the company should re-calculate or negotiate with customers through another model to transfer the extra profit to the customers and make them accept the new purchase method in order to achieve Pareto optimality. In addition, we conduct a simulation regardless of what the price is; the customer only accepts the existing material used at a certain percentage (X).

Through analysis result, the customer only accepts 1%~4% of existing material in the new project. Even for a variety of discounts provided by the company, the percentage of recycled material used by customers maintains a certain level due to safety concerns; compared to the original purchase model, the overall benefit still increases. The profit from reusing the deteriorating materials also rises, while the waste cost falls. The purchase order for materials in the new project also decreases.

For the customers the company provides them the existing raw materials, and if the discount goes from 25% to 100%, then the change to their profit must also be an increase. The cost for the corresponding vendor will decrease along with the increase in the discount ratio for the customer. For both parties, no matter which proposal is adopted, all costs for the company drop, and so the increased profit can make customers more willing to use the existing material (X) at the compromise of purchase quantity (Q).

***Scenario 4*:** Negotiate either with the supplier or customer

The supplier here promises to buy back the unexpired product, and the customer agrees to use the extended product. In order to increase the validity of the analysis, it is necessary to comply with Pareto improvement during calculation. The benefits for supplier, case company, and customer cannot be lower than the amounts in scenario 1. Tables 2 and Table 3 present the results of the 4 scenarios.

**Table 2**
**Purchase cost of the 4 scenarios**

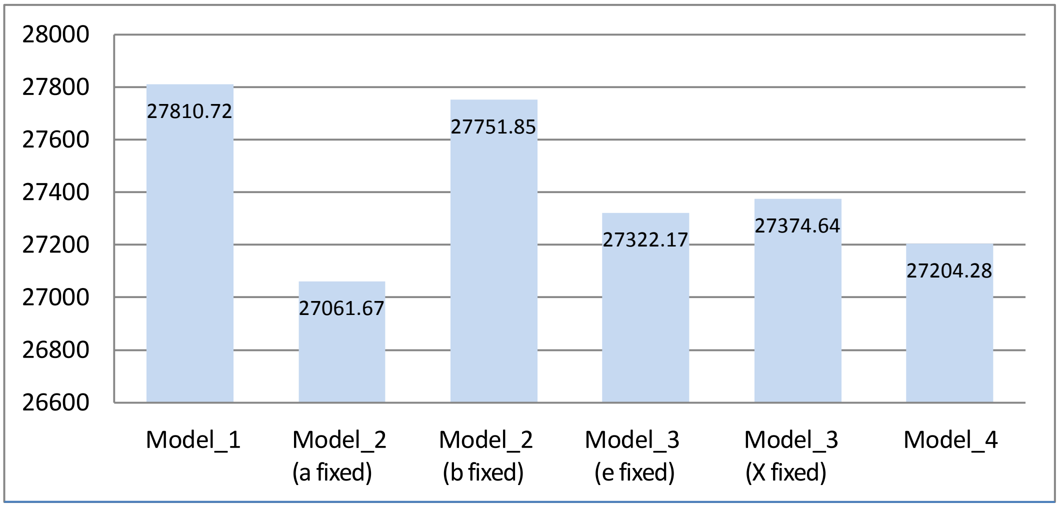

**Table 3**
**Profit change of the 4 scenarios**

| Purchase price increased (a%) | Sales return (b%) | Discount rate (e%) | Product (X) | Quantity of Order (Q) | Repurchasing point (r) | Quantity of scrape (ER) | Shortage (ES) | Order cycle (ET) | Reduced cost (c) | Extra profit of supplier (s) | Extra profit of customer (G) | Profit Change of the entire system |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 25 | 25 | 0.01 | 4.50 | 0.10 | 0.12 | 3.90 | 1.10 | 158.47 | 1931.60 | 13.67 | 2103.74 |
| 2 | 25 | 25 | 0.04 | 4.50 | 0.10 | 0.12 | 3.90 | 1.10 | 249.25 | 1931.60 | 54.66 | 2235.51 |
| 2 | 25 | 25 | 0.07 | 4.40 | 0.10 | 0.11 | 3.90 | 1.09 | 341.57 | 1837.19 | 95.66 | 2274.42 |
| 2 | 25 | 25 | 0.01 | 4.50 | 0.10 | 0.12 | 3.90 | 1.10 | 158.47 | 1931.60 | 13.67 | 2103.74 |
| 2 | 25 | 50 | 0.01 | 4.50 | 0.10 | 0.12 | 3.90 | 1.10 | 144.81 | 1931.60 | 27.33 | 2103.74 |
| 2 | 25 | 75 | 0.01 | 4.50 | 0.10 | 0.12 | 3.90 | 1.10 | 131.14 | 1931.60 | 41.00 | 2103.74 |
| 2 | 25 | 100 | 0.01 | 4.50 | 0.10 | 0.12 | 3.90 | 1.10 | 117.48 | 1931.60 | 54.66 | 2103.74 |
| 2 | 0 | 25 | 0.01 | 4.30 | 0.10 | 0.10 | 3.90 | 1.05 | 30.59 | 3020.50 | 13.67 | 3064.76 |
| 2 | 25 | 25 | 0.01 | 4.50 | 0.10 | 0.12 | 3.90 | 1.10 | 158.47 | 1931.60 | 13.67 | 2103.74 |
| 2 | 50 | 25 | 0.01 | 4.80 | 0.10 | 0.15 | 3.90 | 1.16 | 313.67 | 524.75 | 13.67 | 852.09 |
| 2 | 75 | 25 | 0.01 | 5.20 | 0.10 | 0.21 | 3.90 | 1.25 | 511.92 | -1520.63 | 13.67 | -995.04 |
| 2 | 57 | 25 | 0.01 | 4.90 | 0.10 | 0.17 | 3.90 | 1.19 | 363.72 | 32.40 | 13.67 | 409.79 |
| 2 | 58 | 25 | 0.01 | 4.90 | 0.10 | 0.17 | 3.90 | 1.19 | 370.99 | -39.49 | 13.67 | 345.17 |
| 0 | 25 | 25 | 0.01 | 4.50 | 0.10 | 0.12 | 3.90 | 1.10 | 606.44 | 1439.64 | 13.67 | 2059.75 |
| 2 | 25 | 25 | 0.01 | 4.50 | 0.10 | 0.12 | 3.90 | 1.10 | 158.47 | 1931.60 | 13.67 | 2103.74 |
| 4 | 25 | 25 | 0.01 | 4.50 | 0.10 | 0.12 | 3.90 | 1.10 | -289.49 | 2423.55 | 13.67 | 2147.73 |
| 3 | 25 | 25 | 0.01 | 4.50 | 0.10 | 0.12 | 3.90 | 1.10 | -65.51 | 2177.57 | 13.67 | 2125.73 |

We now provide the simulation results as follows.

(1) Scenario 1: With other things being on the same baseline, the proportion of existing material used in a customer's new project is higher (X=0.07), and the overall profit increases at a maximum scale (2274.42). For the customer, under the circumstance without a safety concern, a higher proportion of such material is used, and thus greater cost is saved. For the company, increasing the price by 2% in the original purchase contract can enhance the value of residual material and decrease the demand for material in the new project.

(2) Scenario 2: Here, all three parties compromise with (a = 2%; b = 25%; X = 0.01). Through data simulation and analysis, the overall profit increases by

2103.74%.

(3) Scenario 3: Under the circumstance that the supplier does not offer any discount for recycling the material, when a, e, and X are fixed (A = 2%; e = 25%; X = 0.01%), the overall profit rises by 3064.76%. If the other conditions (b = 25%; e = 25%; X = 0.01%) are unchanged, then when the purchase price of the supplier increases by 4%, the overall profit is maximum at 2147.73%. Subject to Pareto improvement, the result of Pareto optimality for overall profit is a = 2%, and the overall profit rises by 2103.74%.

From the analysis results, after negotiating with the supplier and customer separately for the three new solutions (Scenarios 2-4), we find that the cost to the three parties can be reduced. Thus, there is strong motivation to adopt a new solution through the mode of project material and profit sharing.

## 5. Conclusion and managerial implications

The development of the inventory model has changed over the years from the model of traditional economic order to supply and demand under various scenarios, such as concerns in the supply chain, inventory in phases, consignment sales, promotions, newspaper deliveries, refunds, etc. Along with product items continually growing, operation systems have also changed due to the environment or even the pursuit of perfection for humanity. In fact, the thinking and models of inventory management are constantly being updated, with gaps waiting to be smoothed and honed. Firm performance is highly affected by both internal resources and the external environment (Han, Chao and Chuang, 2012). Taiwan currently has around 200 small- and medium-sized enterprises in the aerospace manufacturing industry that help facilitate the global demand for aerospace ODM, OEM, and maintenance operations. Firms in this industy can combine TOC and an entrepreneurial orientation strategy and rapidly react to market changes through proactive corporate management strategies. The entrepreneurial orientation strategy includes learning orientation, shared vision, commitment to learning, and open-mindedness, which guide a firm toward a learning orientation organization.

This study explores the gap in the literature based on deteriorating products in the aerospace industry. This industry has many unique industrial characteristics, such as security, which is the most important issue of all. Products of this industry have unique characteristics and supplier mechanisms, resulting in issues of inventory management. This study presents a full analysis of four scenarios that can be a reference for all kinds of companies in the aerospace industry.

Aiming at the four scenarios: such as the inventory model in the company, the inventory model for the company and upstream supplier, the inventory model for company and the downstream customer and integrating the simulation analysis for trilateral inventory model for the upstream, midstream and downstream sites. It is found that through the communication among partners, there will be more flexibility for order , prices and impacts on various points of purchase order quantity, reorder quantity in inventory management.

For negotiating with suppliers (scenario 2), a buyback policy not only increases suppliers' profit, but also reduces material cost for manufacturing companies. Suppliers can resell the material to other manufacturing companies. Furthermore, the price for a buyback of materials can be classified subject to their specialty (commonality).

To negotiate with both customers and manufacturers (scenario 3), a policy to reuse common materials for a project will help decrease customers' contract cost along with costs for the manufacturing companies. For customers, after safety inspection, the material ordered by the last project can be reused for a new ODM project or for maintenance. For manufacturing companies, even if the contract price decreases, due to lower inventory order costs (unnecessary orders) and holding costs, the overall cost still decreases. Additionally, suppliers, customers, and manufacturers all benefit more under continued procurement of long-term contracts (scenario 4).

The objective of this study is to design Pareto-improvement schemes, in which at least one individual firm's profit will be better off without making any other firm's individual profit worse. We analyze the minimum expected cost by the case company in order to build up the order quantity and reorder point under a circumstance in which no party loses any benefit. Although no unique status is included in the Chiu (1994) model, it considers various basic costs and purity from the aspect of the scenario. As a result, that study could be modified to fit our own research scenarios.

The parameter setting for the simulation analysis in this study is based on the actual status of the aerospace manufacturing industry - namely, the material demand is estimated according to the number of planes in order to meet the actual status. Different from other industries, the request for material requirements is very restrictive in the aircraft manufacturing industry. The traditional calculation mode of production cost is based on the design of the purchase contract and cannot be applied to the whole aircraft manufacturing industry. Through systematic calculation, this study includes material purchase, reuse, and recycle into the production cost calculation from the upstream supplier to the downstream customer. By way of different models, possible changes to the input factors are attempted to reach possible Pareto improvement. The simulation analysis result shows that the production model proposed herein helps to increase the profits of both upstream and downstream cooperative vendors. The suppliers, case company, and customers have different profit ratios that increase under different circumstances (scenarios 2-4).

Future research can depend on the different bargaining powers among the partners, and through other economic models like the Stakelberg model, one can calculate possible prices for bargaining and profit allocation among vendors under various situations. The majority of TOC and replenishment model literature is limited to cross-sectional surveys, neglecting the longitudinal viewpoint (Chou et al., 2012). First, there are differences in bargaining power for the case company when encountering different customers or suppliers. Second, it is the fact that the case company’s situation is influenced by the normal business cycle. Third and finally, a firm’s core problems may be raised from corporate strategies, which are too complex to solve with just TOC and the replenishment combined model.

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