School of Innovation, Design and Engineering

Logistics Optimization:

Application of Optimization Modeling in Inbound Logistics

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Khanittha Arayapan

Piyanut Warunyuwong

Report code:
Commissioned by: Khanittha Arayapan and Piyanut Warunyuwong

Tutor (company): AnnChristine Strigen

Tutor (university): Sabah Audo

Examiner: Sabah Audo

Abstract

To be a market leader, low cost and responsiveness are the key success factors. Logistics activities create high cost reducing competitiveness of the company, especially for the remote production base. Thus, logistics activities which are delivery planning, freight forwarder and delivery mode selection must be optimized. The focusing area of this paper is inbound logistics due to its big proportion in the total cost and involvement with several stakeholders. The optimization theory and Microsoft Excel's Solver is used to create the standard optimization tools since it is an efficient and user friendly program. The models are developed based on the supply chain management theory in order to achieve the lowest cost, responsiveness and shared objectives. 2 delivery planning optimization models, container loading for fixed slitting and loading pattern and container loading for pallet loaded material, are formulated. Also, delivery mode selection is constructed by using optimization concept to determine the best alternative. Furthermore, freight forwarder selection process is created by extending the use of the delivery mode selection model. The results express that safety stock, loading pattern, transport mode, and minimum order quantity (MOQ) significantly affect the total logistics cost. Including hidden costs, long transit time and delay penalties, leads freight forwarder selection process to become more realistic and reliable. Shorter processing time, ensured optimal solution, transparency increase and better communication are gained by using these optimization models. However, the proper boundaries must be defined carefully to gain the feasible solution.

Keywords: logistics optimization, supply chain and logistics management, operations research, delivery planning, delivery mode and freight forwarder selection

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Contents

1. Introduction

1.1 Company background

Mölnlycke Health Care is a world leading manufacturer of single-use surgical and wound care products and services for the professional health care sector. The mission of the company is to *be "a global company that provides outstanding solutions for safe and efficient surgical procedures and gentle and effective wound healing"* [1].

Mölnlycke Health Care's business is divided into two divisions, the surgical division and the wound care division, which have 62% and 38% of sales respectively. The surgical division offers safe and efficient surgical solutions through a wide range of single-use products in order to minimize the risk of infections for patients and protect health care workers. Key brands include BARRIER®, Biogel® and HiBi®. The surgical division also offers custom produce trays, known as Procedure Pak®, that add value by reducing time and resources needed to prepare a surgery delivery and cost efficiencies. The wound care division offers gentle and effective wound healing and provides a range of unique products based on a patented soft silicone technology, Safetac®: e.g. Mepilex® and Mepitel®, together with surgical, absorbent and fixation dressings, e.g. Mepore ®. The assortment also has supplementary portfolios in compression, dermatology and orthopedics, as well as products for hard-to-heal wounds, Xelma®, extra cellular matrix protein [1][2].

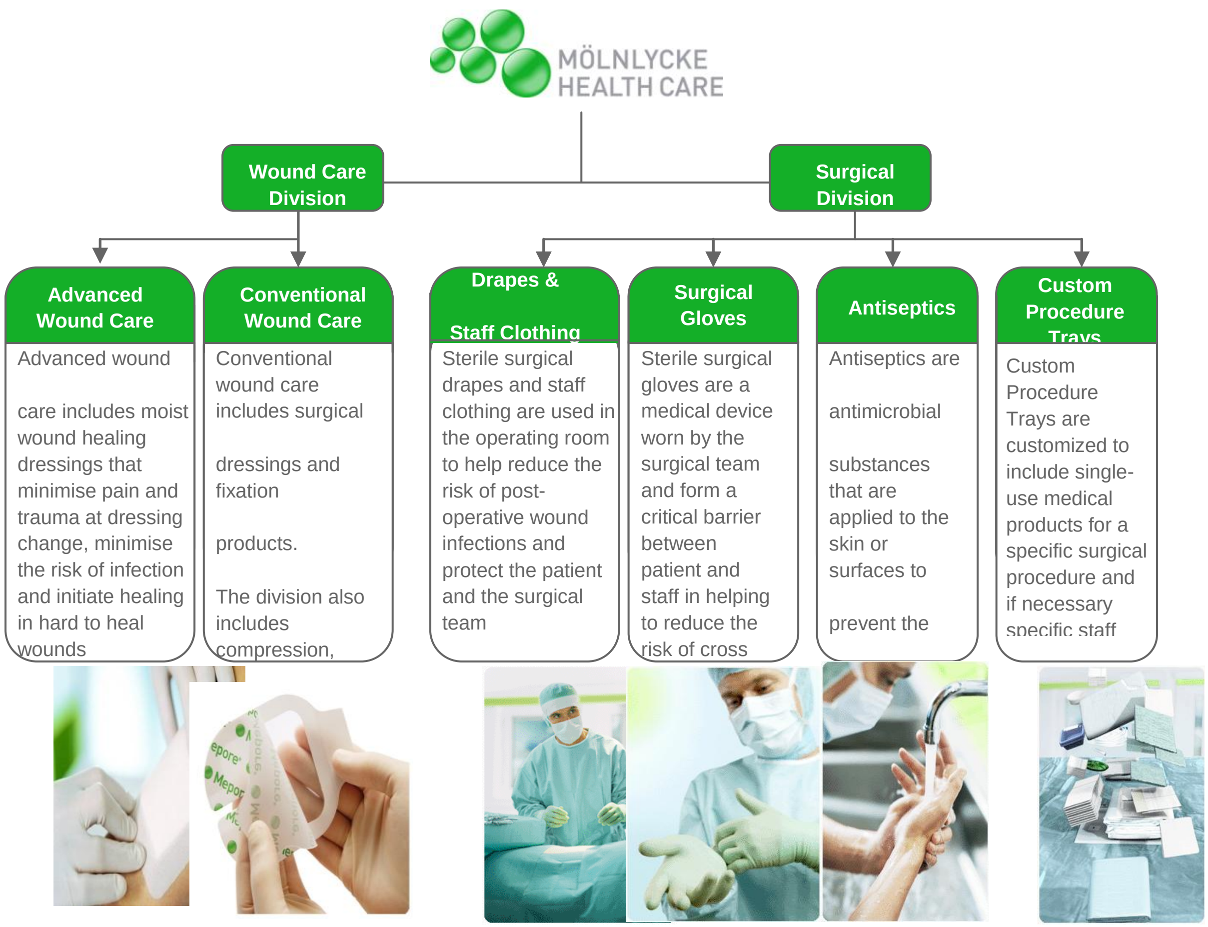

Figure 1 Company's Divisions and products [1][2]

Mölnlycke Health Care started operations as an independent company in 1998 and was acquired from Apax Partners by Investor in January 2007. Currently, the company has about 6,200 employees and manufacturing plants in Belgium, the Czech Republic, Finland, France, Malaysia, Thailand, and the U.K as well as having suppliers producing in China, Japan, Dominican Republic, and US etc [1].

The Thai factories in where this thesis focuses are the important subsidiaries under surgical division as they contribute 44% of the company's factories production income. There are two factories, TH16 and TH18, which have 1,600 employees in total and produce surgical gowns and drapes brand Barrier. The production is labor intensive. Because of quality restriction, 90% of material value or 65% of total article numbers used in Thai factories are imported from the qualified overseas suppliers. In addition, the large amount of these imported materials is bought with the incoterms (international commercial terms) EXW (Ex Works) which have the deliveries handled by the company and CIF (Cost, Insurance and Freight) which the suppliers are responsible for the deliveries. The company's materials classified by delivery term and country of origin are shown in Table 1 [2].

Table 1 2009 budget categorized by value and number of article

Categorized by		Value (%)	Number of Article (%)
Overseas		**90**	**65**
Delivery term	CIF	47	16
	EXW	43	49
Country of origin	US	47	25
	Europe	40	38
	Asia	3	3
Local		**10**	**35**

Reference: Company's 2009 material budget for Thai subsidiaries

To be able to focus on the core competence, the company uses the freight forwarder to handle the EXW shipments. After several years of using the only one freight forwarder for every shipment, recently the company has decided to change the strategy to select one more competitive freight forwarder to compete with the existing one. To work with dual-freight forwarder, the shipments will be divided to 2 main routes, US and Europe origin. The freight forwarder who has the competitive price with the acceptable performance will win the tender and takes care of all shipments in the route. These freight forwarders are responsible for all aspects of the freight without interference in choice of carriers, ports or terminals from the company.

1.2 Problem background

Today's market condition becomes more volatile and causes more pressure on cost and speed. Due to high competition in the globalization market and the more demanding customer, the product life cycle and time to market become shorter, price competition is tougher, and the responsiveness to changing demand is more crucial. Beside high product quality, total cost and response time seem to be the key success factors and important missions that the company and its supply chain and logistics functions have to optimize in order to achieve the cost and service leadership.

Because the production of surgical gown and drape is labor intensive, the Thai factories which have low labor cost and efficient production system offer the strength and competitive advantage with low production cost. However, the factories locations are remote from suppliers and customers, the factories endure the high logistics cost and time. Nevertheless, the company realizes this hinder and tries to lessen it by implementing several projects such as S&OP, Value Engineering, and Procurement excellence program to increase the supply chain and logistics performance. The logistics optimization proposed in this paper is another idea to increase supply chain and logistics efficiency through mathematical programming.

Principally, the business context and the optimization concept have the same goal. They both try to reach the objective functions that are maximizing profit or minimizing cost bounded by the certain constraints which are the limited resources, budget, capacity, and so on. Therefore, the company should take the optimization concept as the framework to carry out in every process to achieve the maximum level of the desired competitive advantages, the cost leadership and service leadership.

Since these two objectives are somehow conflict to each other, the company has to trade-off these conflicting goals reasonably. The systems optimization which includes all desired objectives and related costs and constraints in the calculation will help the company make the effective and efficient logistics decision and design.

There are several decisions made in different functions and progression of supply chain processes which each of them affects the overall logistics costs, time, quality, reliability, and utilization which are the major logistics performance. The optimization tools are required to trade-off between these conflicting goals to get the optimal solution which gives the lowest cost but best performance (time, quality, utilization), especially in the essential and costly processes: the freight forwarder selection, the delivery mode/ route selection, and delivery planning, for instance.

Moreover, the current decision makings concerning supply chain and logistics cost and time are done by the responsible functions individually and separately. Some costs and constraints from the other functions may not be included in the consideration. Also, the current tools are not designed in respect to the optimization concept. Therefore, the standard tool and method for optimization are needed to ensure the efficient decision making and enhance the information transparency and better communication within the organization

The current MRP calculation, for example, is designed based on singular item basis. When the company wants to utilize the container space by combining all materials from the same source or supplier in the same shipment, SAP, which is used to manipulate MRP, can not calculate the best delivery for the combined shipment. The material planner would have to manipulate it manually with Microsoft excel. Consequently, different planners may utilize different methods of calculation and get different answers depending on skill and experience. Therefore, the standard tool and method with all relevant costs and constraints from concerning parties are needed for the most effective decision making.

Besides, the decisions such as selection of supplier, freight forwarder, delivery route, delivery mode, and purchasing and planning parameters setting (e.g. minimum order quantity, safety stock, etc) are also the important activities significantly affecting on the overall organizational cost and performance. Hence, all concerning costs and impacts should be taken into consideration in order to choose the optimal value that best meets the organization's shared objective.

1.3 Aim of project

The aim of this project is to develop tools and methods in order to aid the supply chain and logistics functions in making efficient and optimal decisions. The focused areas are freight forwarder selection, delivery mode and route selection, and delivery planning. With the mathematical programming optimization's ability to determine the optimal solution which is the minimum overall costs or maximum profit, the lowest overall logistics cost with best delivery time and performance under provided resources and constraints is expected to be achieved.

The standard optimization tools and method are also expected to ensure the efficiency and transparency of the decision making. Moreover, the communication within the supply chain would be improved due to the same standard tools deployment.

1.4 Problem statement

Mölnlycke Health Care is a global company, thus, several decisions are made by respective functional units. As a result, the objectives priority of all functions is different which affects on each other's operation. For example, ordering restrictions such as whole pallet purchase may cause higher material and inventory cost. On the other hand, if the ordering amount is not full-pallet, it will cause several problems in warehouse management. Moreover, the insufficient sharing of knowledge and information may not provide the system optimization. Furthermore, some hidden costs such as cost of delay and long transit time are difficult to be determined; consequently, the selection has tended to focus more on the material/service price. Moreover, the current tool works with singular item basis rather than the integrated optimization, so the users need to create the extra tool to make a decision which it has never been proved that is the optimal solution. Finally, decision making efficiency depends on the company's personals' experience and skill. Therefore, standard working process and decision should be set up being assured that all decisions are made in the most suitable way.

1.5 Project limitations

The scope of the study will be limited to the procurement and supply of the imported materials and logistics service for Barrier production in Mölnlycke Health Care Thailand. Although the company's supply chain includes the activities of production and distribution from the manufacturing sites to the distribution center, the project will exclude them from the scope of work in order to focus only the inbound logistics. However, the tools and methods developed in this project are expected to be the models which can be adjusted for use of other supply chain and logistics functions and other branch of the company.

In order to test the validity of the optimization tools, the specific cases are chosen as the samples

- Delivery of materials from supplier X for Drape production in one plant of Thai factory is selected for the delivery choice optimization with fixed slitting and loading pattern.
- Shipment from supplier Y is selected for the container loading optimization for pallet loaded material, delivery mode selection, and freight forwarder selection.

2. Methodology

An action research is used to conduct this research. The authors were participated in the organization and assigned to search for the way to optimize the logistics performances of the inbound logistics.

The research strategy of this thesis is a case study. The current situation of a company was studied and explained how and why it has happened. Then the involving variables and cause-and-effect relationship were identified, and recommendations were created to improve the process. Generally, it can be called as explanatory case study [3].

The following four steps have been performed this research.

1. Data gathering

   Both primary and secondary data collection techniques are used in the thesis in order to get quantitative and qualitative information for analysis. Working process observation and interview with the company staffs and management have been done to gain the primary data. Several meetings with different functions were set to get all related information. Moreover, historical data such as supplier performance, standard working procedure, supplier evaluation, for instance, are used as the secondary data. Also, the quantitative data from the existing working spreadsheets and the company's ERP system were accessed and collected.
2. The raw data received from the company has been analyzed and converted to the desirable form and unit in order to formulate the mathematical models.
3. Recently, there are several optimization programs in the market. Each of them provides different advantages and disadvantages. Microsoft Excel Solver has been chosen to apply in this thesis because of its usability and availability.
4. In the test and validation process, the models have been tested in the actual circumstance. Subsequently, the result of the model has been compared to the actual outcome in order to eliminate all flaws. Consequently, the validity of the model is assured that the models represent the actual processes.

3. Theoretical background & solutions methods

3.1 Supply chain and Logistics management

In a competitive global market, companies inevitably have to reduce cost. Regarding cost contribution, raw material is a major part of the total cost. Therefore, the companies seek for low cost suppliers from various distant locations for common and more specialized raw materials [4]. As a result, logistics cost is also a significant cost contributor, considering the number of suppliers and the distance from the suppliers. In order to lower suppliers cost, logistics is, thus, a very important aspect to consider.

There are several terms referring to logistics, for example, logistics is the organized movement of materials, information, and sometimes people [4] or Rushton *et al*. gave an equation to express that "*Logistics = Supply + Materials management + Distribution"* [5]. Obviously logistics management, especially global logistics management, needs a variety of skills such as buying skill, logistics knowledge, and so forth.

3.1.1 Logistics Trend

As logistics is an important key to become a successful company, there are several parameters affecting the capability of logistics; new product development and order fulfillment, for instance. Logistics system can be depicted as follows;

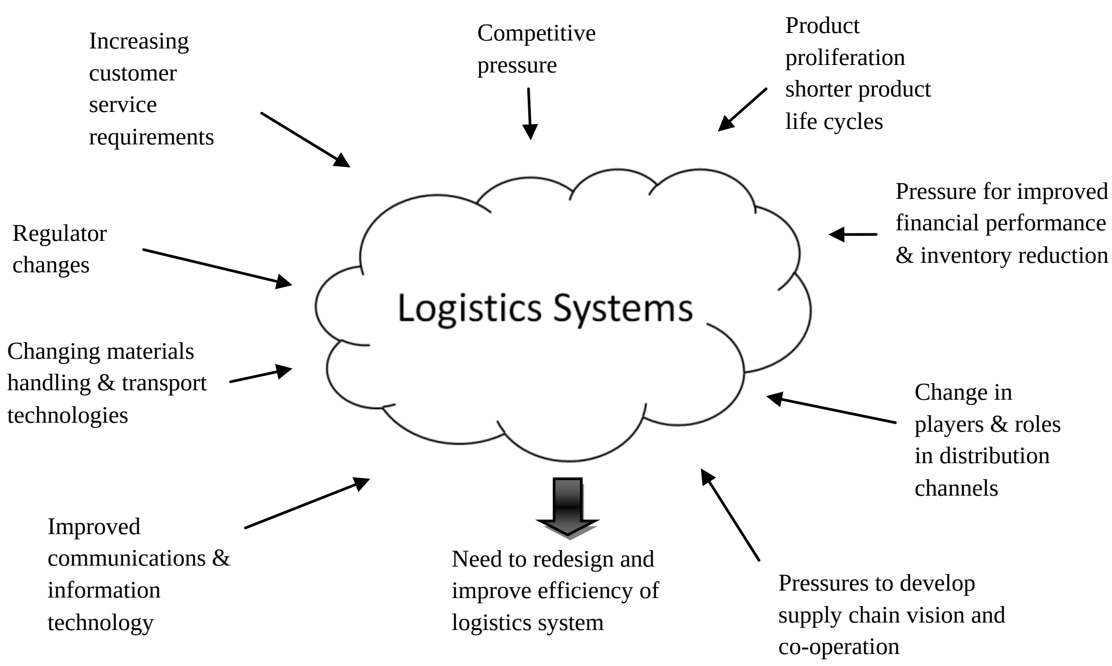

Figure 2 Pressure influencing logistics system [5]

The foremost goal of logistics is satisfying customers' demands with effective cost. This idea is supported by Michael Porter who mentioned that a successful company needs to provide the various products at a low price. Previously, companies have tried to reduce cost by looking for cheaper supply while customer service level might be reduced. However, if the investment in logistics is increased without consideration of the proper customer service level strategy, the expected profit cannot be reached. Thus, new trend of logistics activity is traded-off on cost and customer service level, known as customer value. Waters et al describes that customer value is a ratio between perceived benefits and total cost of ownership of each customer [6]. Inputs used to calculate customer value should be defined circumspectly because some costs such as opportunity cost and hardly tangible costs can be ignored easily. All in all, a company responding more rapidly to customer requirements at lower costs becomes a leader in the market.

Some companies do not want to invest considerably in logistics assets which might affect on companies core businesses, thus logistics outsourcing and third-party logistics are answers to overcome the logistics issues. On one hand, single logistics activity, transport and warehousing, for examples, cannot cope with the overall logistics problems. Therefore, third-party logistics companies (TPLs) offer several kinds of logistics services which cover planning, controlling, and monitoring services. This allows the companies to manage the whole logistics activities. Advanced information technologies and logistics facilities are provided by TPLs to have higher level of agility in logistics as well as gaining economy of scale. The number of TPLs has grown rapidly though logistics outsourcing cost has greatly increased which is a consequence of their ability to provide value-added services such as custom clearance and brokerage, freight forwarding, cross-docking and shipment consolidation, order fulfillment, and distribution [7].

3.1.2 Logistics and supply chain management

Logistics and supply chain management is an activity to optimize material and information flows along the supply chain with the purpose of meeting the customer demand. The aim of logistics and supply chain management is extending the logistics upstream to the suppliers as well as downstream to final customers to gain the highest profit and spend the lowest cost [8]. Integration of all function units in the market channel is the basis of logistics management philosophy. The link between the market and supply chain can be expressed as follows;

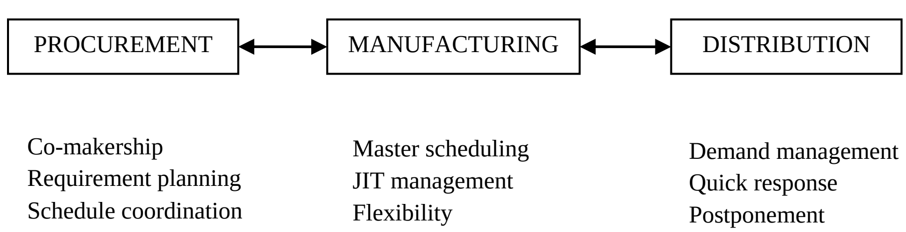

Figure 3 Critical linkage in the supply chain [8]

Normally, procurement strategies have been made to reduce cost of material which is the biggest proportion of the total cost. However, procurement decisions and procedures are not only influenced by the cost, but also the innovation and lead time which depends on the relationship with suppliers considerably. The concept of co-makership has been expressed by Christopher

(2006) which is the mutually beneficial relationship between supplier and buyer in place of adversarial posture deteriorating other advantages in the supply chain [8]. The co-makership is a longer-term relationship which adopts process alignment and synchronization from the customer to the supplier. There are many tools to develop the co-makership such as electronic data interchange (EDI) and open communications with real-time data sharing, which can reduce lead time and eliminate inventories.

Manufacturing

Traditional perception of manufacturing increases non-production cost in the factory such as inventory cost and facilities investment. Therefore Lean philosophy has been used in manufacturing processes for decades to eliminate waste of which associated cost would be reduced. Recently, many companies have also concerned about agility which is the ability to provide various product types and volume within shorter lead time. To respond to the unstable market, higher cost may be unavoidable. Thus, the company must consider both agility and cost, so-called "flexibility". Flexibility can be created by several methods such as one piece flow, where a product is made one at a time. Nevertheless, one piece flow cannot be implemented in all processes as a result of process uncertainty. Subsequently, capacity booking which is a reservation of a fixed cycle capacity is agreed in order to produce many kinds of products according to the real demand. In addition, the lowest-cost products can be produced as work-in process inventory, and then final products which are the higher-cost source will be manufactured only when real demand is known. As a result, the processing time can be decreased.

Distribution

Transport and warehousing were previously perceived as parts of supply distribution. However, distribution is an information-based, valued-added activity which links the marketplace and the factory together. For a successful company, the substantial task of distribution is demand management which is the process of anticipating and fulfilling orders against defined customer service goals [8]. Demand management performance is a consequence of information input quality which comprises sale forecast, production schedule, inventory status, and so forth. Thus, improved information system is increasing information accuracy and reinforcing response speed. Quick response has been invented in order to enable an organization to achieve cost reduction and quicker response of which real demand is shared throughout the supply chain. In order to respond more rapidly, the amount of product transported must be smaller; it results in higher transport cost, but lower inventory cost. Trade-off between transport and inventory cost must be designed carefully to reach the company's strategies. In addition, postponement can gain more flexibility and minimize inventory by producing generic products for the whole market and assembling customized products to response to the real demand.

3.1.3 The new competitive framework: the four Rs

Customers always seek for companies who can provide higher level of customer value. Formerly, competitive advantages were based on four P's; product, price, promotion, and place. Unfortunately, 4 P's cannot respond to the recent market. Thus in place of 4 P's, four Rs: reliability, responsiveness, resilience, and relationships were created to increase level of customer value and to be a guideline for a new logistics trend.

Reliability

Because of more competitive market, every function unit, including customer, in the supply chain has to reduce cost; inventory must be reduced and delivered to the customers on their demand punctually, for example. The company strategy must also emphasis on reliability as a prime objective. Process design and control which are related to information fastness and accuracy are the keys to enhance logistics reliability. Tools such as RFID and barcoding make the system more reliable. Moreover, supply chain management can simplify the process because the process is considered as the whole process rather than fragmented basis. Non-value-adding activities are discovered, then the numbers of hand-offs can be reduced. As a result, there is a possibility to decrease errors in the chain. Furthermore, a lead logistics service provider (LLP) is used to control quality and guarantee the due date, which imposes charges, can be set up. Normally, buyers who purchase several commodity sources tend to work with LLP.

The main reason for unreliability in the supply chain is performance variability. Six-Sigma implementation reduces variations in the process by identifying the cause of variability and using statistical tools to control the process performance. Six Sigma logistics will be discussed in the later section.

Responsiveness

Responsiveness is the ability to respond to the customer demand quickly. Quick response logistics is a term of transporting smaller quantities directly to the point of use within the shorter lead time. The core activity to reduce time is eliminating non-value-adding activities. This implies the number of tasks operated is reduced. Even some cost may increase as a result of eliminating redundant stages; however, the final result is cost effective. Another important key influencing responsiveness of the logistics system is information transparency. If there are some obstacles or difficulties to approach information, time to respond to the real demand will be extended as well.

Resilience

One of the market characteristics is being dynamic, so there are, constantly, risks and uncertainty. Especially in the global supply chain, risks are higher and more difficult to control. Thus, buffers in forms of inventory and excess capacity, for instance, are created in order to absorb risks; however, number of buffers depends on customer service level strategies of the company. Buffers are not made in all nodes but normally only in the critical function units. Besides, audit risk team should be set up to follow up the risk management policies whether all risks are still managed and mitigated.

Relationships

Due to wider range of product requirement, the number of stakeholders also increases. The relationships within the supply chain have higher importance. Furthermore, logistics management is a thread connecting the inbound and outbound flows. Accordingly, the strong relationships with supplier network can augment the possibility to improve quality, reduce cost, and response quicker. For example, good relationship creates trust between the supplier and the customer, so the real data is shared and the vendor can see customer demand directly to prepare the capacity and replenishment instead of waiting for placed orders. This sort of relationship can be identified as vendor managed inventory (VMI).

Previously, logistics improvement is not so much concerned because of difficulty in measurement. Some companies operate vertical organization which is a hindrance to develop logistics system. Contrary, horizontal organization enhances company competence with information system that see-through information since forecast until inventory exists. The organization structure of the international company should be based on full integration with the core business to triumph over culture barriers and geographic obstacles. The system such as ERP allows the supply chain to become truly demand-driven by means of shared information.

3.1.4 Agile Supply Chain

Agility is defined as a comprehensive response to the challenges posed by a business environment dominated by change and uncertainty [9]. For a company, the agility means capability of turning continually and unpredictably changing customer opportunities into profitability. In addition, the ability to match supply with demand under ever increasing levels of volatility can be defined as the agility [10]. Generally, it can be categorized into four sub-groups, with different focus, that is, strategies, technologies, systems and people [11].

The agile supply chain has a number of characteristics as follows [10]:

- Market sensitive: That means being closed to the end users trend in the market and being able to seize the opportunity by reacting to the changing trend rapidly.
- Virtual: In agile supply chain, virtual organization is extended by sharing information among all the whole supply chain partners.
- Network-based: Flexibility is obtained by using the strengths of specialist players.
- Process aligned: An agile supply chain is of high degree of interconnectivity between the network members.

3.1.5 Responsive Supply Chain

By using market knowledge and virtual corporation to catch the profitable opportunity, flexible manufacturing such as agile manufacturing is needed to tackle the changing market condition; however, agile manufacturing only focuses on speed and flexibility not concerning on cost. In contrast, lean production which is developed to reach goal of reducing the cost by eliminating unnecessary non-valued adding activities, lacks speed and flexibility. As a result, there is a need to develop an effective supply chain which is flexible, rapid and cost concern at the same time. The responsive supply chain which is defined as *"a network of firms that is capable of creating wealth to its stakeholders in a competitive environment by reacting quickly and cost effectively to changing market requirement"* combines all qualities needed [12].

3.1.6 Transportation Management

Because of the recent global logistics, transportation management is essential. The fraction between transport cost and the total cost depends on the product's properties. Sand and coal, for instance, creates high transportation cost proportion of its total cost while electronics appliances have less transportation cost fraction. Also, transportation mode affects on responsiveness and agility in the supply chain. Normally, transport mode is chosen according to customer service level of products and characteristics of transportation type which are dependability, time-in-transit, market coverage, flexibility, loss and damage performance, and ability to provide more than basic transportation service. Transport is performed by various modes, motor, rail, air, water, and pipeline, for instance.

An international transport route comprises several kinds of transport mode. Generally, water mode plays an important role in the international logistics activity. In addition, because of the combination of different transport modes, there are many hand-offs which may create a difficulty in an agreement of payment and responsibility. Thus, Incoterms are developed and issued by the International Chamber of Commerce (ICC) in order to facilitate international trades. It is a codification of international rules for the uniform interpretation of common contract clauses in export/import transactions involving goods [13]. There are thirteen terms in the current version which has been validated in 2000. In summary, all thirteen terms can be depicted in Fig. 4 below:

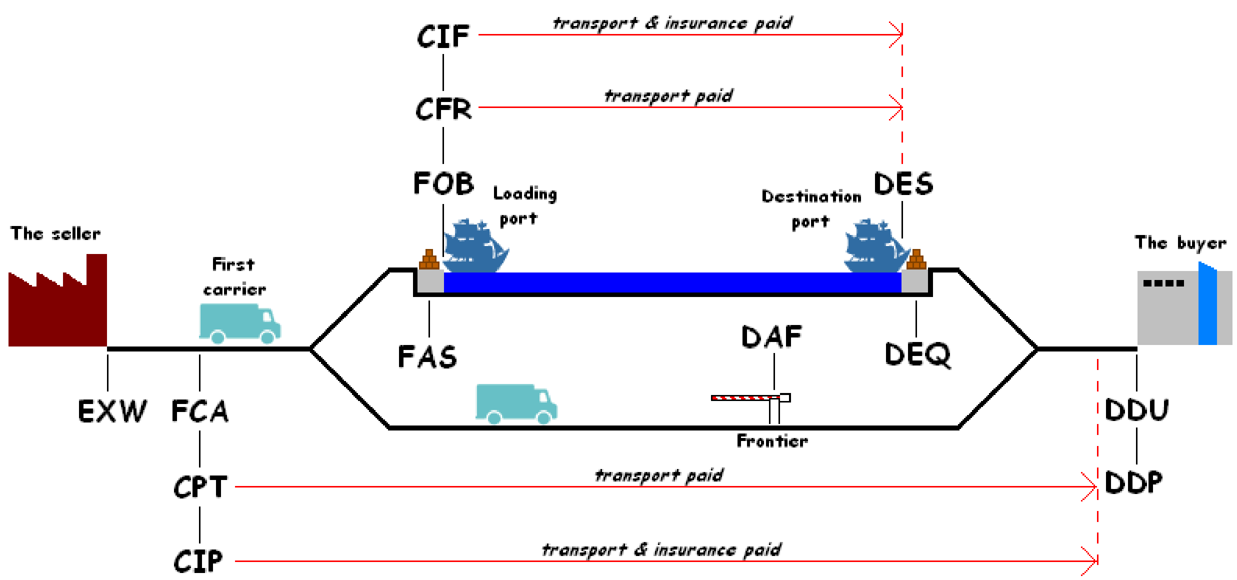

Figure 4 Incoterms 2000: Transfer of risk from the seller to the buyer [14]

<u>Note:</u> *(1) EXW: Ex Works, (2) FCA: Free Carrier, (3) FAS: Free Alongside Ship, (4) FOB: Free On Board, (5) CFR: Cost and Freight, (6) CIF: Cost, Insurance and Freight, (7) CPT: Carriage Paid To, (8) CIP: Carriage and Insurance Paid To, (9) DAF: Delivered At Frontier, (10) DES: Delivered Ex Ship, (11) DEQ: Delivered Ex Quay, (12) DDU: Delivered Duty Unpaid, (13) DDP: Delivered Duty Paid [13]*

3.1.7 The role of logistics service providers in European market

The international business creates a complicated logistics network and uncertainty. As mentioned that logistics providers can offer more reliability in logistics; therefore, logistics service providers play important roles to reduce cost and time of the operation. However, the company should make a clear extent of service providers' roles in order to guarantee satisfaction of manufacturers and customers. Two aspects which are normally concerned by logistics providers are geographical scope and range of services. Airlines and shipping lines, for instance, are nodes to link several units together as a network. In the geographical feature of European market, it is a challenge to logistics service companies to provide one-stop shopping because one-stop shopping has already existed in some European companies. However, the scope of logistics services in European market has extended to final assembly of products, product tracking and tracing, and inventory management; it is far beyond the general services such as documentation services [15].

3.1.8 Logistics cost calculation

The cost of logistics can be combined by different components according to the analysis such as US logistics cost surveyed by Herbert W Davis & Company (2005) comparing to European logistics cost survey arranged by A T Kearney: it is illustrated in Figure 5.

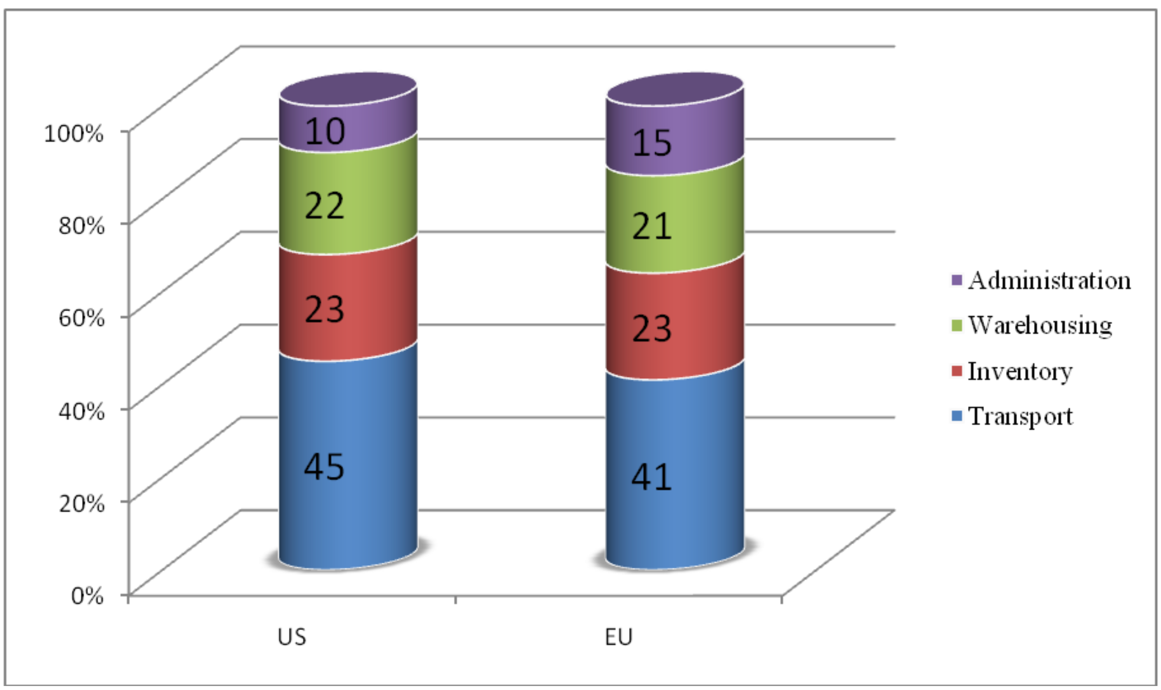

Figure 5: The proportion of US and European logistics cost [5]

3.1.9 Influencing factors

Due to the complex relationship of influencing factors affecting on logistics cost, the management should make a decision on the logistics strategy which can result in many ways. Besides, each parameter should be understood clearly because it affects on the overall performance and cost. Consequently the proper logistics trade-offs must be obtained in order to become a successful company. Table 2 summarizes the effect of trade-off strategies on finance, production, distribution, and marketing [5].

Table 2 Some potential trade-offs in logistics, showing how different company functions might be affected [5]

Trade-off		**Finance**	**Production**	**Distribution**	**Marketing**
Longer production runs		Lower production unit costs	Lower production unit costs	More inventory and storage required	Lower prices
Fewer depots		Reduced costs	No impact	Less complicated logistics structure	Service reduction due to increased distance of depots from customers
Lower finished good stocks		Reduced costs	Shorter production runs higher production unit costs	No need to expand storage facilities	Poorer product availability for customers
Lower raw material and component stocks		Reduced costs	Less efficient production scheduling due to stock unavailability	Lower stock-holding requirement	No direct impact
Less protective transport packaging		Reduced costs	No impact	Reduced transport modal choice	Increase in damaged deliveries
Reduced warehouse supervision		Cost savings through lower headcount	No impact	Reduced efficiency due to less supervision	Lost sales due to less accurate order picking

3.1.10 Transport performance measures

Transport is a major task of logistics service and it is also the biggest proportion of total logistics cost. Therefore, transport improvement is a key to let the company be competitive in the market. To develop the transport performance, four criteria which are finance, productivity, quality, and response time should be focused and measured. Each factor, in turn, consists of many terms; terms in finance, return on logistics assets and logistics asset turnover indicate financial performance. However, which parameters to adopt depend on the company’s concentration and strategies. In the next paragraph, it expresses general measurable parameters in each criterion.

- Financial metrics: Normally, total transport costs and associated ratios such as fleet assets are measured in order to include the capital consumption, especially a fleet owner-company.
- Productivity metrics: The utilization and productivity of transport asset such as containers and vehicles, also operator are evaluated. Weight and volume used are the keys for calculating the transport productivity performance. Regarding [16], there are formulas to determine container utilization:
    - CU = Max {Cube utilization, Weight utilization}
    - Cube utilization = Occupied cube/(Length x width x height)
    - Weight utilization = Load weight/Container weight capacity

For vehicle utilization is calculated from vehicle operating hours (VOH), vehicle available hours (VAH). The ratio of the operating hours to the available hours of vehicle indicates vehicle utilization, for instance.

- Quality metrics: This indicator emphasizes on reliability and damage measurement. The parameters reflecting suppliers' performance are percentage of claimed shipment, damage rate, on-time arrival percentage (OTAP), on-time departure percentage (OTDP), and so forth.
- Cycle time metrics: Because time is factually money in the transportation industry [16], transit time, loading and unloading times, detention time, and delayed in traffic time are related to cycle time performance. In some points, cycle time is influenced by the company's capital. Due to several parameters affecting on the transport time, time breakdown analysis can aid logistics managers to detect the bottle neck of the chain easily and reinforce the opportunity to improve the logistics performance.

3.1.11 Performance monitoring

In order to monitor four aspects of transport performance, information which is an important input should be quantitative and comparative. Besides, the information used in the system should be accurate and timely in order to observe performance successfully. Performance monitoring is a cyclical activity starting with current stage study, after that indentifying the distribution process objectives. The next step is developing appropriate strategies to achieve plan objectives, followed by process control and comparing to the plan. As mentioned, the performance monitoring is a cyclical procedure; therefore, continual review and revision of plans must be progressive.

Balanced scorecard

Performance monitoring process is normally unplanned and unrefined which can create complexity and incompleteness of the process. In general, there are several ways to guide performance monitoring procedure such as the balanced scorecard. Kaplan and Norton introduced this method in 1996. Balanced scorecard is a tool to translate the strategic missions to measurable objectives by using Key Performance Index (KPI) [5]. There are four aspects to consider, which are financial perspective, customer perspective, internal perspective, and innovation and learning. All KPIs of four perspectives should be set up to balance all aspects in order to achieve the business's goal.

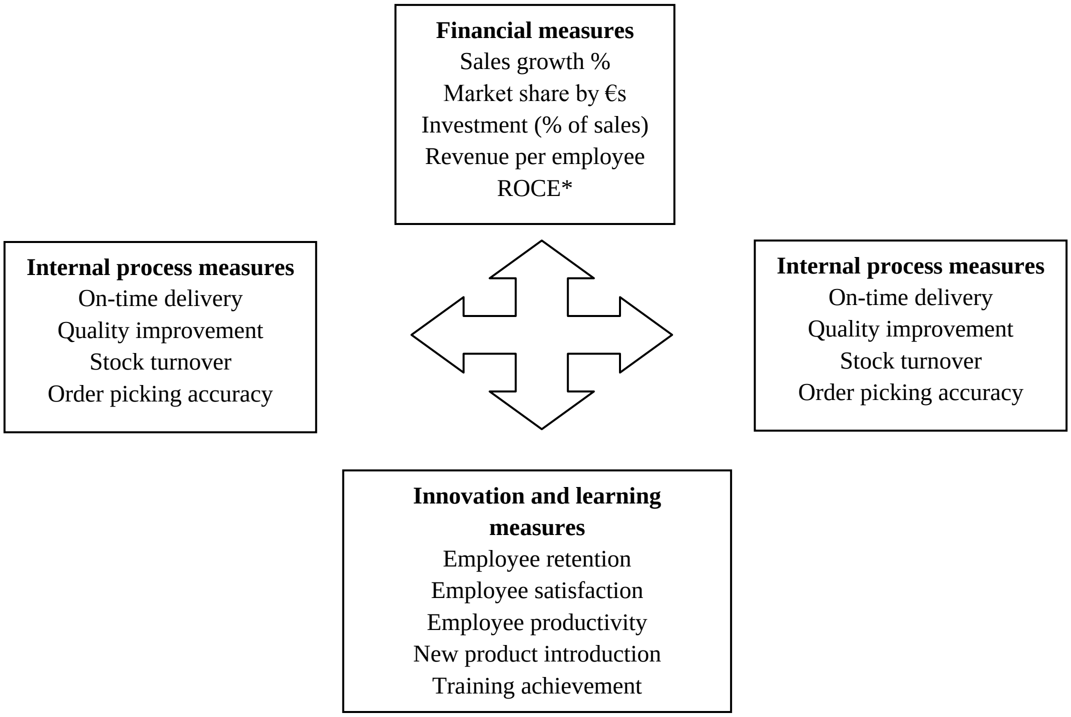

Figure 6 Balanced scorecard: typical measurements [5]

** ROCE = Return on capital employed*

3.1.12 Lean Six Sigma logistics

The concept of logistics management is cost reduction and quality improvement. Several companies have implemented lean and Six Sigma in logistics operation. Lean philosophy is about eliminating waste, particularly excessive inventory to decrease lead time and increase velocity by focusing on the total cost rather than cost in a single unit. Whereas, Six Sigma concept emphasizes on studying to remove the negative effects of variation in processes by getting customers' feedback and using statistical process control tools to ensure accuracy and reliability of the process. Both concepts support continuous improvement activities. In general, Lean Six Sigma Logistics can be defined as "the elimination of wastes through disciplined efforts to understand and reduce variation, while increasing speed and flow in the supply chain" [17].

The proportion of lead time and cost caused by transport is significant, also the cost of unreliability and delaying, unsatisfied customers are difficult to identify and handle. Therefore there have been attempts to improve transport system. "Six Sigma" concept in transport improvement is to minimize time and variation of average transport time. There are several causes of waste and variation, outdated equipments and poorly trained drivers, for instance. What is more, to manage transport efficiently, managers must understand that the logistics network comprises inbound and outbound links. Formerly, companies only regarded outbound flow of material due to market response and allow suppliers or production planners handle inbound flow of materials. As a result, suppliers will add up unexposed transportation cost in material cost; this leads to difficulty in transport management. Thus, many companies take charge of the inbound transportation as well. Nonetheless, some companies have chosen to use freight forwarders with whom the management must maintain proper relationship. Long term relationship with shippers can let the company get the lowest priced transport service, but sometimes it causes excess inventory or exceeding customer requirement level. In consequence, logistics network must be optimized as “a big picture” cost trade-offs.

Focusing on the individual shipment, causes of inefficient transport are poor utilization of equipment, operators, and other limited resources. However, some companies have not considered the cause of waste, though they can be rectified: multiple less-than-truckload (LTL) shipments in the same route can be consolidated as a truckload and stops at intermediate destinations where the number of damages may be reduced if the products need to be sorted at each intermediary.

3.1.13 Supplier Selection Process

The effectiveness of supplier selection and evaluation process is the key success factor of a supply chain since cost of materials is the major contribution in the product cost. Consequently, cost and quality of material has a direct impact on the cost and quality of products. By selecting the right supplier, the company can significantly reduce product cost and increase corporate competitiveness [19].

The general processes of global sourcing can be divided into 5 stages [18].

1. Investigation and tendering: The organizations do the market analysis and business plan, then set the global sourcing strategies and establish the operational plan and performance measurements accordingly.

2. Evaluation: Develop supplier selection criteria and estimate target cost and benefit required.

3. Supplier selection and development: Select the best supplier, conduct the negotiation, do the assessment, and schedule the implementation.

4. Implementation: Assign the working team in both parties, construct the supply and logistics agreement, set the performance target and begin to measure the actual performance.

5. Supplier performance and continuous improvement: Assess the effectiveness of the operations and collaboration in order to identify causes of problems and seek for improvement to become excellence.

Generally, a supplier is selected because of their competence to meet company’s expectation on quality, price, and delivery performance. However, other factors such as reputation in the industry, size of enterprise, geographical location, environmental compliance, capacity, services, lead-time, packaging, transportation storage, and product are also essential and can not be ignored whatsoever. The importance of each factor depends on the product type and its market condition [20]. Therefore, supplier selection is a matter of trading-off the multiple conflicting tangible and intangible, quantitative and qualitative, strategic and operational criteria in the most cost-effective way [19].

The high impact on the corporate success and involvement in various conflicting criteria make the supplier selection becomes one of the most important and difficult decision makings in the supply chain and logistics management. Nevertheless, the combination of all important tangible and intangible factors with strategic and operational factors such as quality, delivery, flexibility and so forth with consideration of relevant constraints in the analysis improves the validity of the decision [19].

3.2 Operations research

One of the techniques used to aid a decision making is operations research (OR) method. In general, operations research technique is used widely to solve the problems existing in the reality, especially in the operation management. Nowadays, there are several fields using operations research methods to optimize theirs operations such as manufacturing, transportation, and so forth. Inventory system and production planning are the most successful areas by obtaining the advantages of the operations research. In addition, there are a lot of techniques used in the operations research, linear programming and integer programming, for instance. Among several techniques, linear programming model is mostly used in production planning because of its simplicity and effectiveness.

The characteristics of the operations research result in broad applications in various parts. In order to create a model, the problem is studied and all relevant data are gathered, and then the scientific model is formulated to describe it. Generally, mathematical method is used to explain the relationship among several parameters and constraints into equations, consequently the problem becomes tangible. Furthermore, the model must be validated for the real situation by using it in several experiments. In this step, it can be called as *model validation*. Moreover, the operations research can reduce conflicts which normally happen in a decision making. The best solution for the whole system is provided by including all interesting parameters into the model. Therefore, an operations research team should be an arrangement of persons from several backgrounds such as mathematics, statistics, computer science, and economics. However, the model ought to be created in the appropriate scope which is not too specific to optimize the whole organization; on the other hand, the model must be particular enough due to convenient use.

The operations research procedure consists of six steps, problem definition and data gathering, mathematical model formulation, computer programming, model test and refinement, preparing the model application, and implementation.

Problem definition and data gathering

The first step to solve the problem by the operations research team is studying the problem. Suitable objective and possible constraints are determined to express the relationships between the focused area and other parts of the organization. Also, data must be collected with problem understanding in order to obtain the accurate data in the appropriate unit.

The proper objective is crucial since the model is used to support the management's decision. Furthermore, the objective of the model must regard the organization as a whole rather than a single unit. Nevertheless, taking into consideration of the entire organization can cause difficulties and a clumsy model which may result in the imprecise objective. Normally, the objective function is set to provide the maximum profit or minimum cost combining with other objectives, for example, product assortment, workers' morale improvement, and so forth. Therefore, five parties which are owners, customers, employees, suppliers, and nation must be concerned to create the model.

A mathematical model formulation

Generally, the core of the problem is represented by the mathematical model regarding the interrelationships and aiding to facilitate the system analysis. Moreover, the model can disclose cause-and-effect interaction of the problem. In an optimization model, decision variables, normally known as x_1, x_2, …, x_n, present quantitative decisions which are needed to determine. The desirable performance is a function of the decision variables such as the total cost, $C = 1.5x_1 + 2x_2 + \dots + 6x_n$. Also, restriction of these decision variables can be defined as constraints presented in inequalities or equations. Furthermore, parameters identifying coefficients and right-hand sides are the constant numbers in the constraints and the objective function. However, some parameters are difficult to define, thus values estimation of parameters happens. In addition, there is always uncertainty in the system causing the variation of the solution from the reality. Therefore, sensitivity analysis would be a method to evaluate difference of the model's solution if the parameters changed.

In order to create the model describing the real world problem, it can cause an intractable model. Consequently, model simplification is required to determine the solution while maintain the aim of the model. Model validation is significant to trade-off between the correctness and the tractability of the model. Finally, the objective function should be based on the overall performance measurement by combining several objectives to make the ultimate goal.

Computer programming

The next phase after the mathematical formulating is model development which normally is a computer based procedure. This step must not usually be the most difficult part of modeling the program since there are several available software packages. As mentioned that the model represents the idealized problem, so the optimal solution may not be the same as the best solution in the real world. However, some good model provides the answer which is good enough to be the real world solution, the model needs to be validated and test elaborately. Additionally, the execution must be in the appropriate time, thus a lot of operations research teams occasionally use heuristic procedure to find a suboptimal solution in order to gain the maximum net profit.

Testing the model

Several errors, both major and minor, are regularly contained in the first computer program. As a result, the operations research team must inevitably eliminate flaws in the program before implementing it. In some cases, all flaws can not be removed; however, the major problems must be managed. This process calls model validation which is the testing and improving the program's process to increase its validity. The validating team should consist of at least one person who is not in the model formulation team in order to disclose mistakes. Also, decision variables and/or parameters must be changed to check the solution being in a reasonable conduct. In addition, the model validating process can compare the result of the model with the historical situation called as retrospective test. However, the historical example used in the validation must be equivalent to the prospect condition otherwise the model can not be a representative of the future situation. The document related to the model is also important to improve confidence in the decision making and aid in identifying the causes of the problems.

Preparing the model application

The purpose of the optimization model implementation is providing the optimal solution being independent on personnel. Hence, well-documented system must be installed including the model, solution procedure, and procedure for implementation. Besides, databases and management information system ought to support the model with the aim of providing the latest information.

Implementation

The model implementation phase is significant due to the benefits of the study are obtained at this point. The success of the implementation depends on the management and operating management. So, the operations research team must involve in the beginning of this phase in order to inform the benefits of the model to the management and be assured that the model is used in the proper way. Also, remaining errors can be rectified in this final process. Moreover, the team must acknowledge feedbacks from the operational team and modify the system if it is necessary. After all processes are completed, the related document must be defined clearly, accurately, and sufficiently to run the program well repeatedly.

3.2.1 Linear programming

Linear programming is normally used to solve the allocating resources among competing activities problems [21]. The meaning of *linear* is all mathematical equations are linear functions while *programming* refers to planning. Therefore, linear programming often describes assigning resources to activities. However, it can also be used for several kinds of problem which theirs mathematical models fit to the linear programming format. The objective of linear programming is planning the problems in order to gain the optimal solution.

A standard form of the model

As mentioned that the mathematical model contains the objectives function which is a function of decision variables under the constraints. There are two kinds of objective function which are maximizing profit and minimizing cost. In addition, activities can be formulated as equations or inequalities. Hillier and Lieberman (2005) expressed the data needed for a linear programming model as in Table 3.

Table 3 Data needed for a linear programming model involving the allocation of resources to activities [21]

Resource	Resource Usage per Unit of Activity				Amount of Resource Available
	Activity				
	1	2	…	n	
1	a_{11}	a_{12}	…	a_{1n}	b_1
2	a_{21}	a_{22}	…	a_{2n}	b_2
.					.
.	…	…	…	…	.
.					.
m	a_{m1}	a_{m2}	…	a_{mn}	b_m
Contribution to Z per unit of activity	c_1	c_2	…	c_m	

In summary, the standard form of maximizing profit can be expressed as follow [21].

$$\text{Maximize } Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n$$

Subject to the restrictions

$$a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \le b_1$$
$$a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \le b_2$$
$$\vdots$$
$$a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \le b_m$$

and

$$x_1 \ge 0, \qquad x_2 \ge 0, \ldots, x_n \ge 0$$

In contrary, the minimizing cost formulation can be shown as follow.

1. The objective function:

   Minimize $Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n$

2. The constraints are in inequalities:

$a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n \geq b_i$ for some values of i

3. Or some functional constraints are in equation form

   $a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n = b_i$ for some values of i

4. Define the value of decisions variables:

   x_j unrestricted in sign for some values of j

3.2.2 Integer Programming

For the optimization models, many problems are reasonable only when the decision variables are integer, for example, the model determining the optimal number of machines. Namely, it is an integer programming problem which normally still is the linear programming problem. In some cases, however, the decision variables can be integer combining with non-integer, thus, the problem can be defined as mixed integer programming. On the other hand, pure integer programming is the problem containing all integer variables. In generally the application of integer programming is popular in investment analysis, site selection, designing a production and distribution network, and so forth.

Binary variables in model formulation

One of the purposes of optimization is decision making which means the decision variables are yes-or-no. Hence, *binary variables* or *auxiliary* binary variables are used to change and intractable problem become a pure or mixed integer programming problem. Binary variables are normally fit in the linear programming and integer programming or the problem which there are minor disparities [21]. There are various cases utilizing auxiliary binary variables represented by y_j combining with the original variables x_j to solve the problem.

Either-or constraints

For some optimization models, one constraint must be chosen from two possible constraints in order to provide the best solution. Thus, M which is a very large positive number is applied. Also, y, an auxiliary variable being either 0 or 1, is multiplied with M to eliminate the undesirable constraint. In contrary, the product of 1-y and M pledges the existing of the other constraint. From [21], the example can be expressed as follows.

Either $3x_1 + 2x_2 \leq 18$
Or $x_1 + 4x_2 \leq 16$,

Using M, y, and 1-y to define the desirable constraints

$$3x_1 + 2x_2 \leq 18 + My$$
$$x_1 + 4x_2 \leq 16 + M(1 - y)$$

According to these equations, if y was equal to 1, the second constraint would be chosen to hold, whereas if y was 0, the first constraint would be *yes* to the first equation.

K out of N Constraints Must Hold

For this case, it is similar to the previous problem where K equal to 1 and N equal to 2. In other word, the general description of this kind of problem is there are K constraints must hold among N possible constraints when K<N and N-K constraints are removed. The common form of constraints can be formulated as below [21].

$$f_1(x_1, x_2, \dots, x_n) \leq d_1$$
$$f_2(x_1, x_2, \dots, x_n) \leq d_2$$
$$\vdots$$
$$f_N(x_1, x_2, \dots, x_n) \leq d_N$$

Then, the same logic as previous case is applied to defined K constraints must hold and vice versa for N-K constraints.

$$f_1(x_1, x_2, \dots, x_n) \leq d_1 + My_1$$
$$f_2(x_1, x_2, \dots, x_n) \leq d_2 + My_2$$
$$\vdots$$
$$f_N(x_1, x_2, \dots, x_n) \leq d_N + My_N$$

$$\sum_{i=1}^{N} y_i = N - K$$

and

y_i is binary, for i = 1,2, …, N

Functions with N possible values

The situation that there are several possible right-hand-side values of a constraint may happen and only one value provides the best solution. Thus, auxiliary binary variable is used to change it to an integer programming problem. The constraints can be denoted as [21]:

$f(x_1, x_2, \dots, x_n) \leq d_1$ or $d_2, \dots,$ or d_N

Subsequently, the integer programming can be created as follow.

$$f(x_1, x_2, \dots, x_n) = \sum_{i=1}^{N} d_i y_i$$

$$\sum_{i=1}^{N} y_i = 1$$

and

$$y_i \text{ is binary}, \quad \text{for i = 1,2, …, N}$$

The fixed-charge problem

In an operation, the cost is normally the summation of a fixed charge or set up cost and variable cost depending on the number of activity level. Normally, the total cost can be presented by the following form [21].

$$f_j(x_j) = \begin{cases} k_j + c_j x_j & if\ x_j > 0 \\ 0 & if\ x_j = 0, \end{cases}$$

For example

Minimize $\quad Z = f_1(x_1) + f_2(x_2) + \cdots + f_n(x_n)$

subject to

given linear programming constraints

Use an auxiliary binary variable, y_i, to convert the problem to a mixed integer programming problem.

Minimize

$$Z = \sum_{j=1}^{n} (c_j x_j + k_j y_j)$$

where

$$y_j = \begin{cases} 1 & if\ x_j > 0 \\ 0 & if\ x_j = 0 \end{cases}$$

Moreover, M is used to be assured that y_j is 1 more willingly than 0 when $x_j > 0$. Thus, the fixed-charge problem is adapted to the mixed integer programming as following.

Minimize

$$Z = \sum_{j=1}^{n} (c_j x_j + k_j y_j)$$

subject to

The original constraints, plus

$$x_j - M y_j \leq 0$$

and

$$y_j \text{ is binary,} \quad \text{for } j = 1,2, \ldots, N$$

Binary Representation of General Integer Variables

The problem containing a lot of binary variables with a few general integer variables can cause a difficulty in the problem solving. Therefore, the general integer programming sometimes is changed to a binary integer programming. This method, the binary representation for each general integer variable is used especially for an integer which is in a range. Hillier and Lieberman (2005) showed the binary representation method as follows.

Range of x; $0 \leq x \leq u$

and N is defined as the integer that

$$2^N \leq u \leq 2^{N+1}$$

As a result, the binary representation of x is

$$x = \sum_{i=0}^{N} 2^i y_i,$$

where y_i variables are auxiliary binary variables. x which is a function of y_i will lead the problem becomes a binary integer programming.

For further understanding of the binary representation method, an example of [21] presents the application as follow.

The problem contains two constraints, x_1 and x_2 that the constraint inequalities are

$$x_1 \qquad \leq 5$$

$$2x_1 + 3x_2 \leq 30$$

In this case, u = 5 and u = 10 for x_1 and x_2, respectively. Thus, N is 2 for x_1 ($2^2 \leq 5 \leq 2^3$) and N is 3 for x_2 ($2^3 \leq 10 \leq 2^4$). The binary representation can be written as

$$x_1 = y_0 + 2y_1 + 4y_2$$

$$x_2 = y_3 + 2y_4 + 4y_5 + 8y_6$$

Then, substitute x_1 and x_2 in the original constraints and the constraints will be

$$y_0 + 2y_1 + 4y_2 \qquad \leq 5$$

$$2y_0 + 4y_1 + 8y_2 + 3y_3 + 6y_4 + 12y_5 + 24y_6 \leq 30$$

The values of y_i are determined to obtained the optimal solution. For example, if x_1 = 3, (y_0, y_1, y_2) becomes (1,1,0) and x_2 = 5 matches (y_3, y_4, y_5, y_6) = (1,0,1,0). However, the disadvantage of this technique is the increase of variable number which may not suitable for all cases.

3.2.3 Process/pattern selection model

Among several mathematical models, the static model - simultaneous production of multiple products by a single activity, which is a special type of process selection problem used when a number of products can be produced from a common material simultaneously by one or more operations, is one of the most useful models for the supply chain and logistics operations. Processing crude oil into petroleum products, crushing stone with a mix of sizes resulting, cutting of apparel parts from the same spread of cloth, cutting multiple patterns of paper from the mother roll, and stamping or cutting multiple parts from sheet metal are the examples of the application. The problem is to meet the requirements at the minimum cost. Let

X_j = quantity of material processed by method j, j = 1,2,…,n

D_j = required quantity of product i, i=1,2,…,m

a_{ij} = contribution of unit of material processed by method j of product i

c_{ij} = unit cost of method j

Z = total cost

The aim is to choose nonnegative X_1, X_2,…, X_n to minimize Z. So, the linear programming formulas are:

Objective function: Minimize $Z = \sum_{j=1}^{n} c_j X_j$

Subject to: $\sum_{j=1}^{n} a_{ij} X_j \geq D_i$, (i = 1,2,…, m)

In addition, the constraints on the amount of material that can be processed by various methods should be added if any [22].

3.2.4 Logistics optimization

The principle of optimization is minimizing or maximizing a quantifiable objective function by changing values of a set of quantifiable constraints. In logistics aspect, optimization is used for several purposes such as minimizing total cost and maximizing utilization, e.g., Frazelle expressed that the customer service policy objective is to minimizing the total logistics costs (TLC) [16]. The constraints are inventory carrying costs, response time costs, and lost sales costs. A mathematical equation can be written as follows;

Minimize:
Total logistics costs = Inventory carrying costs + Response time costs + Lost sales cost

Constraints:

1. Inventory availability > Customer service inventory target
2. Response time < Customer service response time target

The customer service optimization, from the above expressions, is a kind of tradeoff activity, e.g., if the inventory level is high, the inventory carrying cost increases, the lost sales cost will have to be reduced. On the other hand, if the management intends to reduce the lost sales cost by reducing response time; consequently, the transport cost or warehousing cost will be higher.

3.2.5 Logistics System optimization

To optimize logistics system, there are three strategic focus areas, i.e., total cost, horizontal integration, and vertical integration.

Total cost

The system is a complicated network of which all function units have interactions. Because of complex network, all costs are quite difficult to reveal as it is known as implicit costs such as inventory carrying costs. In general, the total cost is a summation between explicit and implicit costs. Explicit cost is a tangible number of expenses such as transport cost, material cost, and so forth; however, in some companies, the costs that should be explicit are invisible. Whilst, implicit cost is a cost if a company does not pay directly, the opportunity in sales, for instance, may be lost. There are several ways to calculate opportunity lost by which the management must consider when making company's strategies.

Optimization is a condition that all function units operate at the optimal level by giving all variables, dynamics, and constraints of the system [17]. Normally, the optimization purpose is to minimize cost, for example, calculate the minimum cost of inventory to get the required customer service level. All in all, the total cost calculated from integrated activities should be applied to optimize entire system rather than using the calculation from single unit tasks in order to reach strategic decisions. Nevertheless, this process needs to be incorporated and understood; some cost may be increased to shrink the cost of the whole system. Then a person, responsible for the total logistics system, such as a vice president of logistics, can effectively manage the total cost.

Horizontal integration

Logistics system can be improved significantly by implementing horizontal integration. The concept of volume driven opportunity in logistics leads to the concern about the total volume instead of the volume in an individual distribution center. This results in enhancing the flexibility of the total system. Moreover, the collaboration between sub-units in the organization is a way to optimize logistics system, e.g., purchasing needs to work with transport and warehouse or warehouse requires the cooperation from a material handling staffs. The barriers to succeed in integrating organization operations are system constraints and the staffs' inconsistency. Thus, mutual understanding of incident problems such as human errors among each unit will create more effective conclusions and positive results to the organization.

Vertical integration

Many wastes such as overproduction can be a result of bad connection along the supply chain. Also, many parameters like economies of scale of manufacturing or uncertain demand from the customers can create losses, e.g., one of the Toyota Production System (TPS) philosophies is to enhance the relationship along the supply chain, so-called "vertical integration", should be implemented. The inputs of integration process are communication, information sharing, and trust [17]. On the other hand, the information that is not actually shared can generate bullwhip effect which is a situation that each supplier stocks their own product until overstock is created. Consequently, substantial planning information is required to optimize the system. Though the information shared along the supply chain is correct; the supply side should set their operation to have high level of variability and leveled flow to cope with uncertainty of the market.

3.2.6 Transportation optimization

The general objective of transport optimization is minimizing transport cost subjected to the customer service policy. Normally, the transport solution affects inventory carrying and warehousing cost considerably; thus, they should be included in the objective function to express the influence by transport solution directly. From an example of Frazelle (2001), response time requirement, time windows, volume requirements, frequency of use should exist in the objective function of transport optimization while constraints are lane capacities, vehicle capacities, container capacities, workforce capacities, and workload imbalances [16]. Nonetheless, this example is merely a guideline to determine an optimal transport solution which must be adjusted according to relevant condition.

4. Current state analysis

4.1 Current process

4.1.1 Material Procurement

In order to gain procurement power from the global volume, materials and logistics service procurement are centralized at the headquarters in Gothenburg, Sweden while the succeeding supply chain processes are conducted in the manufacturing sites. The main responsibilities of the procurement are evaluating and approving the new supplier to ensure that the central suppliers are able to fulfill the requirements in the Supplier Evaluation Report (SER). In addition, price reviewing and negotiation, contract and agreement handling, and performance monitoring and control of the existing suppliers in terms of on-time delivery, completed quantity, material quality, responsiveness on complaints, and completeness of the quality certificate are also the key tasks of procurement and purchasing staffs.

The important decision relating to logistics operations made by this function is the supplier selection and the ordering agreements such as the minimum order quantity, lead time, and payment term. These parameters have the significant effect to the delivery and inventory cost.

The important tools & methods used in the supplier evaluation and performance control are:

- Supplier Evaluation Report (SER) is the standard report used to evaluate supplier's capabilities in different aspects and it is approved by the central buyer of the company. This report is also used for a periodic review.

- The cost comparison is the process to compare cost of material (including logistics cost) proposed by each candidate supplier. The logistics cost is estimated and provided by the Logistics Procurement.

- SIX rate/COGNOS, the performance measurement report system, integrated with SAP is used to measure the supplier performance in 5 criteria, Time: on-time delivery precision, Volume: delivery precision in terms of quantity, Quality: Conformity of material quality with the agreed specification, Responsiveness: response time to the complaint, and Certificate: completeness of quality certificate. The data in COGNOS will be monitored regularly.

4.1.2 Logistics Procurement

The logistics procurement section evaluates and procures the global partner/partners who can be a freight forwarder, a carrier or a combination of them who handles the shipments of material from EXW suppliers to company's subsidiary and/or shipments of finished goods from the company's subsidiary to the distribution center. Because the oil price and freight vary during a year, the logistics procurement has monitored the market situation and searched for the profitable alternatives to handle the company's shipments. Currently, the central procurement controls only the performance of the outbound logistics whereas the inbound logistics cost and performance are managed by the local subsidiaries.

The important decisions made in this section are the Freight Forwarder selection, the agreed delivery mode and route selected, sometimes, the container size to be used has been determined as well.

The current tools and methods used in the freight forwarder selection are the spreadsheets containing the company's budget and the price proposal of each route provided by each freight forwarder to manipulate the price comparison.

The cost and performance control is expected to be done by the logistics manager of each factory. However, the information is sent to the Transport Commodity Manager (Logistics Procurement) when it is needed.

4.1.3 Material Planner

The material planner performs the day-to-day operation with suppliers and the forwarder to supply materials to the warehouse and the plants according to demand requested in the ERP system (SAP). The call-off quantity and frequency of delivery depend on material requirement and ordering parameters set with suppliers and planning perspective such as safety stock level, minimum order quantity, packaging quantity, lead time, and container loading. Currently, the normal delivery mode is only sea freight and the delivery route for each supplier is fixed for only one alternative according to the agreement between the Transport Procurement and the Freight Forwarder. If the material delivery is needed to be expedited, the most frequently used solution is air shipment which is much more expensive.

The important decisions in material planning function are the safety stock setting, period of MRP review, the delivery plan including the proper amount and frequency of the call-off deliveries, the container size, and sometimes the delivery alternatives for the urgent shipment as well.

The current tools & methods used in this function are:

- SAP/R3 is the main tool used in Material Requirement Planning (MRP).The planning parameters such as ordering lead-time, planning cycle, desired safety stock, minimum order quantity, and quantity per package of each material are put in SAP to gain the suggested ordering quantities and dates. For materials which have no delivery or loading restriction, the material planner will place the order as the system suggested. But for materials which have the special restriction of loading such as the combined shipment or the fixed loading pattern, the material planner would have to do further manipulation for the appropriate delivery arrangement in the spreadsheet.

- Several spreadsheets with different formulations are used for different purposes e.g. container loading planning for a combined shipment, MRP of fixed slitting and loading pattern materials, inventory status reports, etc. Furthermore, the planning parameter setting such as safety stock level is done in excel sheets with necessary information exported from SAP.

4.1.4 Freight forwarder

The selected freight forwarder has a responsibility to arrange the delivery from the supplier sites to the manufacturing sites according to the quantity and arrival dates requested by the material planner with the agreed price and transport procurement. Normally, the delivery performance and actual cost has been reported directly to the manufacturing plant for monitoring and control. On the other hand, the current delivery performance is difficult to be observed due to the operational system, SAP, can not separate transport delivery performance from the supplier delivery performance. Besides, the utilization of the container has never been measured and controlled.

The selection of the carrier, the delivery mode, the delivery route, and the container size for each delivery are assigned to be the authority of the freight forwarder deciding upon the agreement.

The current tool & method used for communication between the freight forwarder and the company is the spreadsheet containing all delivery details such as material number, delivery quantity, delivery date. In addition, it is used as the job order released from the material planner to the freight forwarder, the shipment arrangement details responded from the freight forwarder, as well as the shipment follow-up and freight forwarder performance control tool. Also, the spreadsheet is shared among the relevant units who are the material planner, the shipping staff, and the freight forwarder.

Summary of the information flow within inbound logistics functions is shown in Figure 7.

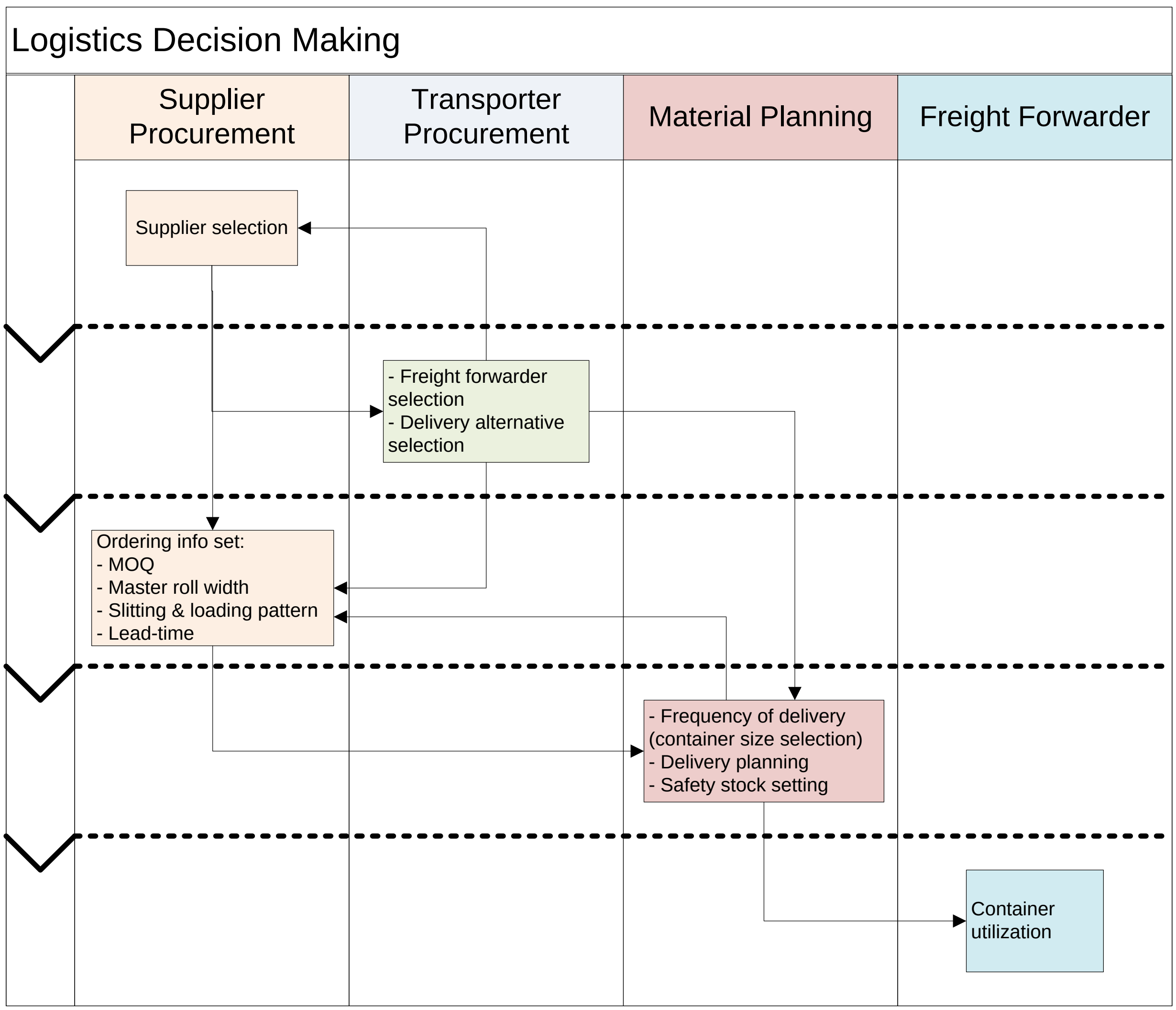

Figure 7 Decision making and information flow of the inbound logistics

4.2 Performance measurement

The delivery performance is mostly measured in 4 aspects, delivery time, cost, utilization, and quality. Although these 4 measurements are the shared objectives of every function in the supply chain, the decision made in each process can either support each other or conflict to one another. Therefore, the optimization has to be done not only for each function, but also for the integrated supply chain functions.

Normally, the on time delivery is the major criterion used to select the freight forwarder. Also, other aspects such as the current history with the company, the competitive price, the creativity, the openness, and IT capability are considered.

Currently, there are 5 criteria to measure the performance of the inbound shipments, the on time delivery, completeness of the delivery (order volume completeness), quality of product, completeness of quality certificate attached with shipment, and responsiveness of quality complaint. However, these performance measurements are evaluating the supplier's performance, not the logistics' performance. Thus, the aspects of logistics such as delivery time, utilization and quality of the delivery have not been taken into consideration. In addition, the damage caused by transportation has never been measured either. On the contrary, the delivery time shows all delays combining supplier's fault with freight forwarder's fault together. In conclusion, there is no performance measurement to measure the performance of the logistics operations handled by the freight forwarder.

Actually, there is presently the monitoring spreadsheet used and shared between the material planning department, the shipping department and the freight forwarder to monitor and follow up shipments' status. Though the use of this spreadsheet should be extended to cover all aspects of logistics performance measurement and used as the feedback for further evaluation. With the combination with the performance measurement system called COGNOS, which has already had the performance measurement for the inbound material supplier and the outbound logistics, the company can create system for the inbound logistics supplier, or in other word, the freight forwarder as well.

4.3 Disturbance Analysis

Like customers in other business, the company's customers declare that besides the desired quality, the customers also want the cost-efficient product, with quick response and short lead time. These requirements pass on the pressure to the supply chain and logistics department to perform the excellent operations to meet the 4 major logistics performance target which are the low cost, short lead time, good quality and high utilization. In order to improve the aforesaid performance indices, the search for the hinder is conducted for further improvement.

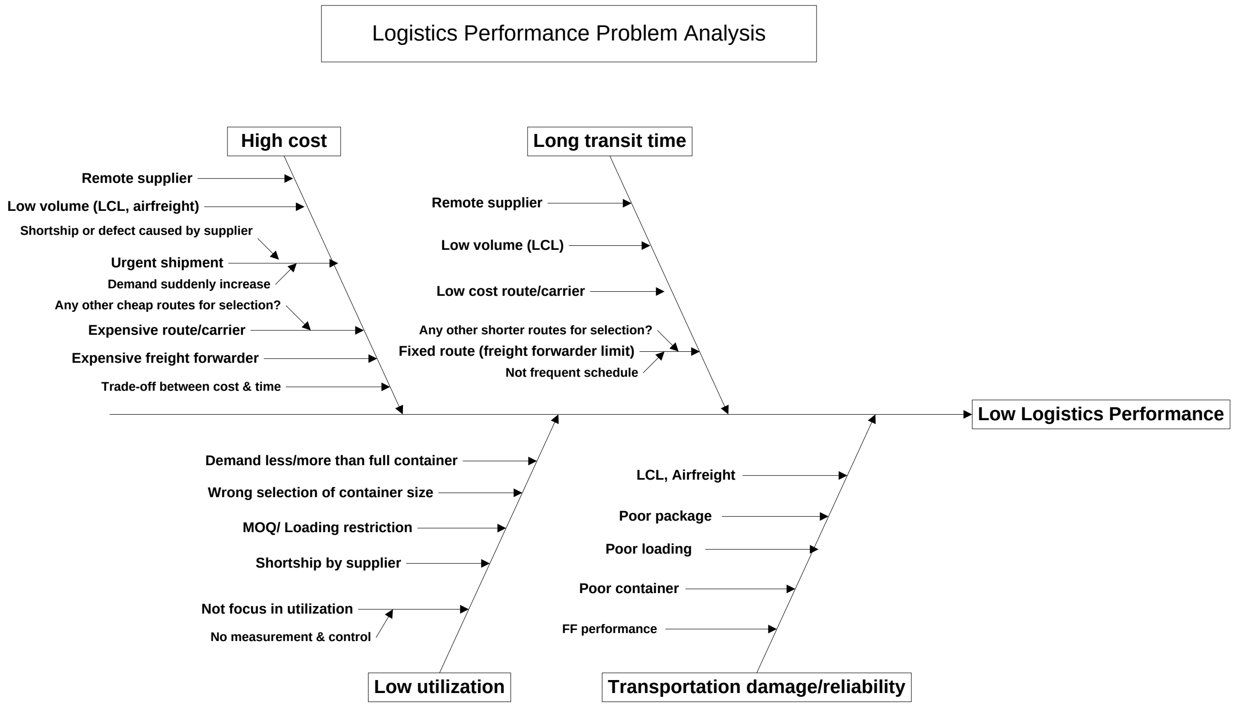

Figure 8 Logistics performance disturbance analysis

In summary:

1. Supplier:

Due to the geographical constraint, the long distance between the company and supplier caused long transit time and high logistics cost. The average transit time from overseas suppliers to Thai sites is 4 weeks approximately while the longest transit time is 9 weeks. The replacement of the current supplier with the domestic or nearer supplier producing same quality of materials will reduce the delivery cost, delivery time, and safety stock. However, the evaluation and trade-off with material price, quality, and other criteria stated in the Supplier Evaluation Report has to be done carefully.

2. Freight forwarder

Sometimes, the freight forwarder is selected because it is dominating in the major route or it has low cost in one container size but not in all. Consequently, there may be problems when the company has to arrange the shipment from where the freight forwarder has limited capability or when the company uses the different container size from its cheapest. Thus, all alternatives with company's requirements should be compared in order to gain the most realistic cost. And besides, in the special route where the company's freight forwarder has the limited offer and less competitive solution, the company should take the competent competitors into consideration.

3. Delivery mode and container size selected

Each alternative has different pros and cons as summarized in Table 4:

Table 4 Characteristics of each delivery mode

	Quantity per delivery (plt)	Delivery time	Delivery Cost	Delivery Quality	Container Utilization	Inventory cost
40' container	20	Long	Lowest	High	Low	Highest
20' container	10	Long	Low	High	Low	High
LCL	1	Longer	High	Low	High	Low
Airfreight	1	Shortest	Highest	Low	High	Low

To select appropriate delivery mode and container size for each route/delivery, the company has to determine the delivery time, the delivery cost, quality, offered utilization, and the inventory cost. Therefore, the selection should meet the demand while having the lowest total costs.

4. Delivery Planning

The level of the delivery planning efficiency has a great impact on all logistics costs and performance. The inefficient planning may cause low container utilization, high delivery cost, or high inventory of excess stock. On the other hand, the decision making in other functions such as the container size selected, minimum order quantity, and loading agreement made with supplier also bring difficulties to the delivery planning and cause the inevitable cost. Therefore, the setting of these parameters should be optimized as well in order to gain the systems optimization.

5. Agreement with supplier

The minimum order quantity and the other agreements such as the slitting and loading pattern have the significant consequence on the logistics planning and logistics cost. The minimum order quantity and fixed delivery pattern may reduce the material unit price and increase delivery utilization; on the other hand, it causes the inventory cost from the excess stock. The trade-off between the unit price reduction regarding the inventory cost and other sequential costs should be considered.

In general, the difficulties in the logistics management can be listed as follows:

Some logistics components and performance measurements are conflict to the others. That causes the conflicting objectives in some functions which have different priorities. For example, the procurement department prioritizes on cost while material planner focuses on time and flexibility. The selection of the cheap supplier or freight forwarder meets cost objective in procurement department but hinders time and flexibility objectives in the planning department. Moreover, some costs occurring in other functions are not included or considered as constraints in the calculation if the information is not shared.

The performance measurements, even though most of them can be translated to the quantitative measurement, different performance aspect has different units which can not be compared directly. For instance, the delivery time aspect can be measured with the transit time used for the delivery whereas the delivery cost is shown in term of money, while utilization is measured in percentage of utilization or waste. Consequently, some decisions were made just by estimation. In order to be able to compare several aspects, the conversion to the same unit is needed.

Hence, the logistics optimization is a matter of balancing the conflicting goals in the most efficient way. The information of constraints and cost should be collected from all related functions. From Figure 8, we can capture 6 major costs occur in the inbound logistics flow.

- Delivery cost
- Inventory holding cost
- Transit time penalty
- Delay cost
- Transportation damage
- Utilization waste

4.4 Cost structure

The inbound material procurement cost is the major cost in the product value. And the freight cost is about 5-10% of material cost. It varies in each supplier depending on four parameters, 1) the distance 2) the delivery mode: sea freight or airfreight 3) delivery type (LCL or FCL) and the container size (20' or 40' container) and 4) the freight forwarder/carrier used.

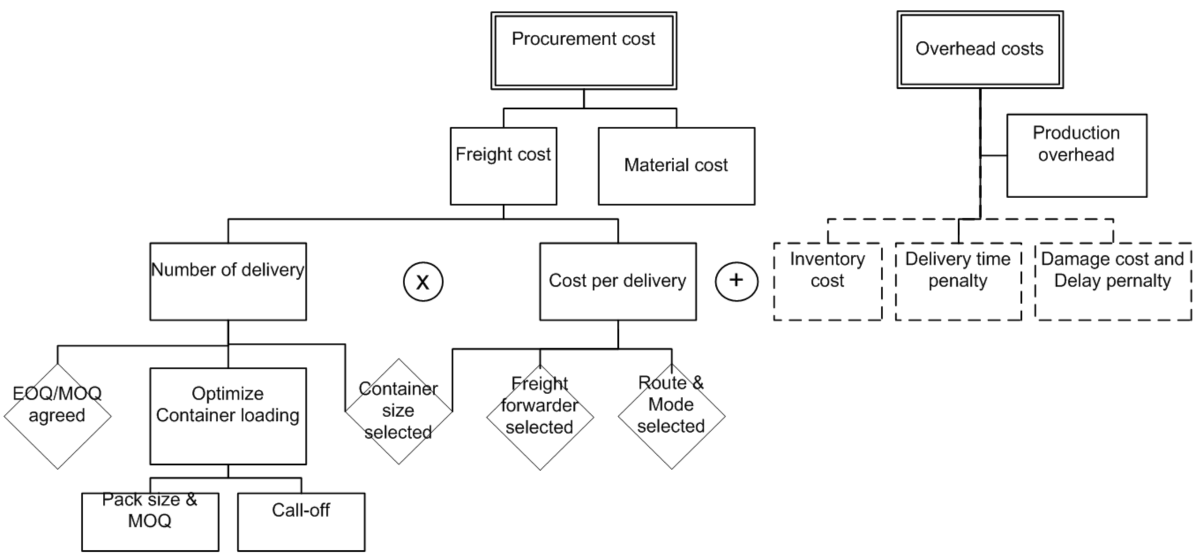

Figure 9 Total material cost breakdown

In the current material cost calculation, only the direct material cost and freight cost are considered whereas the inventory holding cost is shared in the manufacturing overhead cost. However, the inventory holding cost should not be neglected in the logistics planning since it affects the total logistics costs. The logistics cost components are shown in the Figure 9 and explained in details as follows:

Logistics cost comprises 2 major costs, the delivery costs charged from the freight forwarders and the material holding cost occurred in company's warehouse.

The delivery cost charged from the freight forwarder calculated from the multiplication of the number of containers used and the freight rate of each route offered by the freight forwarder.

Delivery cost = Number of container x Freight rate

Number of container = Demand / (Capacity of the selected container size x Utilization)

Freight rate = Freight for each mode and route from freight forwarder

In order to reduce the delivery cost, the company can do the following options:

- Decrease number of container used by selecting the container size that is the most cost-efficient
- Decrease number of container by increasing the utilization of the container: trade-off between delivery cost and inventory cost.
- Decrease freight rate by selecting the cost-efficient freight forwarder: trade-off between transit time and freight cost
- Decrease freight rate by selecting the cost efficient delivery mode and route: trade-off between transit time and freight cost

The material holding cost is the summation of the interest rate paid for the material cost multiplied by the inventory amount hold in each time period and inventory holding cost.

Inventory holding cost = (Inventory amount x interest rate) + (holding cost per unit x inventory quantity)

In order to maintain the low inventory holding cost, the company has to control the inventory quantity to be within the safety stock level which is restricted by the minimum and maximum boundaries.

Currently, the decision made in the logistics operations are manipulated separately and not included some intangible costs such as the damage from transportation, penalties of the long transit time and delay. Hence, the cost saving in some area may cause higher cost in other areas which the optimal solution of the whole logistics is not obtained. In order to optimize the decision making, the mathematical model used in the calculation should put the total logistics costs as the objective functions including all constraints in every process in the subjective functions so that the calculation can fully cover the systems optimization.

5. Applied solution procedures

5.1 Case study 1: The delivery planning optimization

5.1.1 Delivery choices optimization: with fixed loading pattern for the roll materials (Model 1)

Generally, the roll materials are produced in the jumbo size and slit to the required widths and lengths according to the demand and then dispatch to the company in a full container. Currently, some suppliers deliver materials according to the required amount directly but some have the specific slitting patterns of materials and certain loading patterns of the finished rolls. Although some suppliers bear the delivery cost, with incoterm CIF, and the invoices from supplier seem to charge only for the delivered material, the company pays the waste from slitting and container utilization indirectly with a higher price. Therefore, both the company and the supplier have to work hard to find the optimal master roll size, slitting pattern and loading pattern which give the minimal waste and overall costs. However, the slitting and loading restriction causes more complication in the delivery planning as sometimes the unwanted materials come along with the selected pattern and cause high cost of material and inventory. Therefore, when the material planners issue the order, they have to spend quite long time on manipulation for the optimal ordering that meets the demand with the least overall costs including excess stock.

The proposed optimization model uses the integer programming optimization linking the slitting and loading pattern optimization with the traditional MRP. The objective of this model is to determine the ordering quantity of each slitting and loading pattern that minimizes the total costs which comprises material waste, utilization waste, inventory cost and inventory holding cost. The subjective functions are all constraints restricted by the slitting and loading pattern including the required inventory level, or in other word, the set safety stock level.

The interview with the material planner to learn the current method to manipulate the ordering and to get the necessary information to formulate the optimization model was conducted. And then the optimization formula can be modeled as follows:

Objective function: $MinTC = \sum sw_i z_i p + \sum clw_i z_i cc + \sum x_{ij} p_j + \sum y_j ic + CC * \sum z$

Decision variables: z_i

Subject to:

$z_i \geq 0$

z_i = integer

$SS\min \leq y_j \leq SS\max$

Parameters are denoted as follows.

TC = Total costs which include cost of slitting waste, container space waste, material cost, inventory cost, and transportation cost

sw_i = slitting wastes of pattern i (m^2)

z_i = number of container for pattern i

p = material price per m^2

clw_i = container loading waste of pattern i (inch)

cc = transportation cost per inch of container length (USD/inch)

x_{ij} = order quantity of width j in pattern i (rick)

where $\sum_{j=1}^{n} x_{ij} = [z_i] \times [a_{ij}]$, a_{ij} is number of ricks of width j provided by pattern i

p_j = material price per meter of width j

y_j = inventory quantity of width j (rick) where $y_j = x_{ij} + y_{j-1} - d_j$

d_j = demand of width j

ic = inventory cost (USD/rick)

CC = transportation cost per (40') container

SSmin = minimum safety stock (rick)

SSmax = maximum safety stock (rick)

The objective function is to minimize the total cost which is the summation of slitting waste, container loading waste, material cost, inventory carrying cost, and delivery cost. The decision variables are the number of ordered container from each slitting and loading pattern which must be integer and greater than or equal to zero. Also, the constraints are the range of acceptable safety stock and the capacity of warehouse arranged for the delivery from this supplier, if any. The Microsoft Excel's Solver is used as the optimization tool to execute the result as shown in Appendix 10.1.

5.1.2 Container loading optimization – material on pallet (Model 2)

Delivery planning model is created in order to optimize total cost as a function of material cost, inventory cost, and transport cost. This case study is solved by Microsoft Excel's Solver which is shown in Appendix 10.2. The objective is to minimize the total cost. Firstly, 100% container utilization is set to get the lowest transport cost. The model contains only one type of transport mode per one execution which is normally set as 40 feet container shipment which number of pallet per container (N) is 20. Due to 40 feet container shipment is the most economical way of transport and it is normally chosen by the company. In addition, all items purchased must be more than minimum order quantity (MOQ). Moreover, shortage will not occur because inventory is set to be closed to minimum safety stock level, so shortage cost is not included in this model. Safety stock of each item is adjustable depending on demand and service level. Also, the model is designed to make an order of one container per one execution. Therefore, the lowest cost is reached when the total demand is in the vicinity of full containers being noticed by total minimum call-off which is shown as consumption rate. For the fixed ordering period, the proper container size can be changed from 20 feet container by defining N = 10.

According to general Material Requirement Planning (MRP) calculation, related terms can be calculated as

- Call-off = safety stock + demand – previous period inventory; $x_i = ss + d_i - y_{ij-1}$ (1)
- Inventory = previous period inventory + call-off – demand; $y_{ij} = y_{ij-1} + x_i - d_i$ (2)

Parameters are denoted as follows.

x_i = order quantity or call-off (pallet) where i is item and i = 1, 2, …, n
y_{ij} = inventory (pallet), where j is time period and j = 1, 2,…, n
z = number of container, where z = 1, 2, 3,…
p_i = material price per container (USD)
ic_i = inventory cost per pallet (USD)
cc = transport cost per container (USD)
d_i = demand (pallet)
ss = minimum safety stock (pallet)
N = number pallet per container, N = 20 for 40 feet container or
N = number pallet per container, N = 10 for 20 feet container
CO_{min} = minimum call-off (pallet)
CO_{max} = maximum call-off (pallet)
$CO_{min,M}$ = minimum call-off after MOQ adjustment (pallet)
$CO_{max,M}$ = minimum call-off after MOQ adjustment (pallet)

Case A: Full-pallet purchase

One of agreements between the company and suppliers is full pallet ordering. The reasons are regarding warehouse management and transport utilization. Also, the products are produced in batch, thus full-pallet loaded amount is normally used as order quantity.

To purchase in full pallet, the boundary of pallet purchased is very important. For instance, minimum call-off and maximum call-off calculated from the Equation (1) are 0.3 and 0.6 respectively, the model is impossibly feasible.

The constraints of call-off (x_i) are termed as maximum call-off ($CO_{max,M}$) and minimum call-off ($CO_{min,M}$) which both of them regarding MOQ. Number of safety stock setting by the company is one of the components in Equation (1) to define CO_{max} and CO_{min} . Both CO_{max} and CO_{min} are integer by rounding up the result of Equation (1). However, there is the possibility to have call-off less than MOQ. Thus, the selection of the appropriate CO_{max} and CO_{min} which are $CO_{max,M}$ and $CO_{min,M}$ happens. $CO_{min,M}$ is determined according to Figure 10.

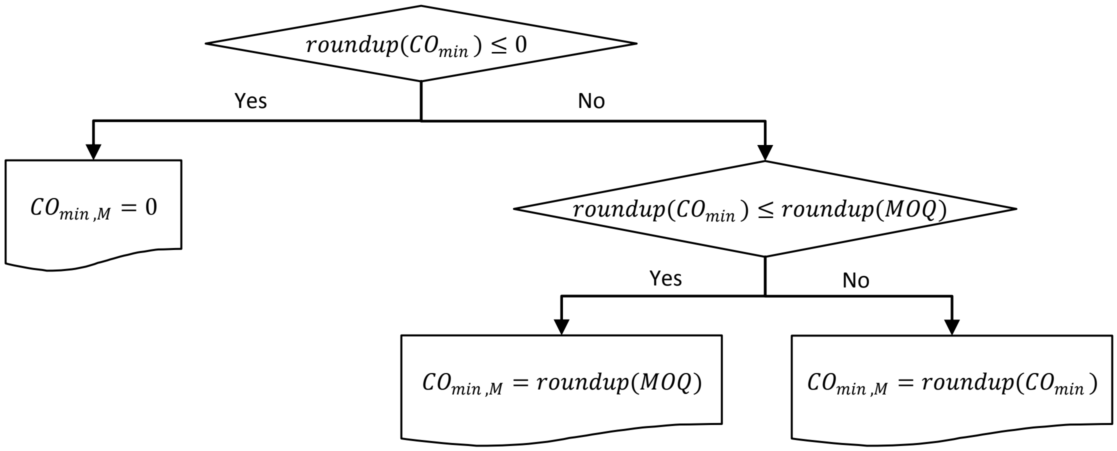

Figure 10 $CO_{min,M}$ selection for case A

Furthermore, $CO_{max,M}$ selection takes place as in Figure 11.

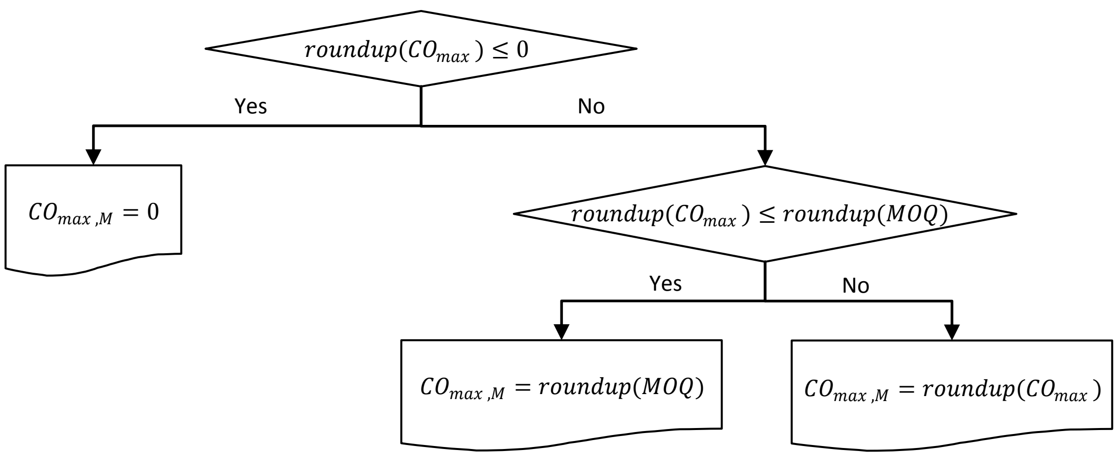

Figure 11 $CO_{max,M}$ selection for case A

Case B: Not full-pallet purchase

Even full-pallet quantity is the most desirable purchased amount; however, there is an exception for some suppliers or products such as an item which the amount per pallet is utilized thoroughly for several months. In addition, manufacturing and quality problem can cause volume incompleteness, therefore, material planners order required amount regardless quantity per pallet. On the other hand, container utilization and MOQ are still a constraint to make an order. Figure 12 and 13 express $CO_{min,M}$ and $CO_{max,M}$ selection procedures respectively.

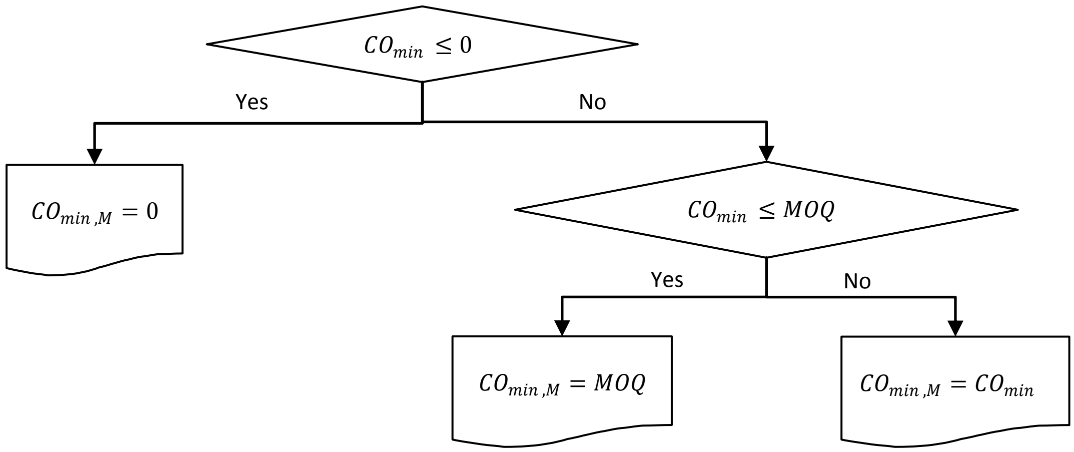

Figure 12 $CO_{min,M}$ selection for case B

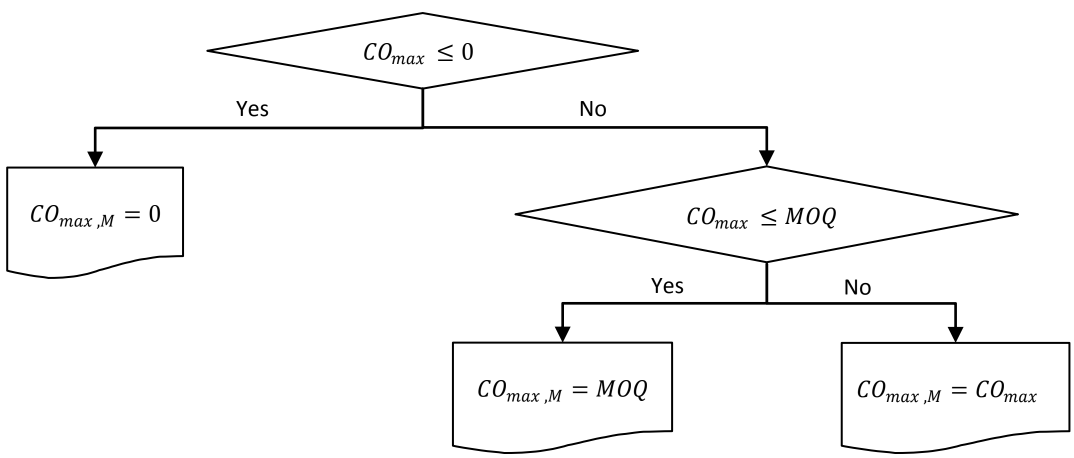

Figure 13 $CO_{max,M}$ selection for case B

Therefore, the model can be programmed as

Objective function: $Min\ total\ cost = \sum x_i p_i + \sum y_{ij}\, ic_i + z.cc$

Decision variables: x_i, z

Subject to: $CO_{min,M} \leq x_i \leq CO_{max,M}$

$z = \frac{\Sigma x_i}{N}$

$x_i, z = integer$ for case A

Or $z = integer$ for case B

As mentioned that the appropriate demand is necessary to be estimated, so call-off period selecting process is needed. In this case study, the demand of week 0912-0924 is considered. Numbers of $CO_{min,M}$ and $CO_{max,M}$ are vital to be concerned otherwise the feasible solution will not be attained. Whether number of container becomes integer or not depending on total $CO_{min,M}$ and $CO_{max,M}$, for example, if the total $CO_{min,M}$ is 9 pallets which is 0.45 container of 40 feet container, the summation of $CO_{max,M}$ should not be less than 20 pallets to allow the optimal number of container to be 1. In general, call-off period covers the demand of one container with the aim of minimizing inventory cost. Therefore, call-off period is the period that total $CO_{min,M}$ is the most reached to 1 in order to take an advantage to obtain the highest consumption rate as well. All in all, $CO_{min,M}$ and $CO_{max,M}$ are the important keys to get the optimal solution.

5.2 Case study 2: The alternative selection

In the selection process, the manager would aim to choose the alternative that gives the most beneficial result whilst meeting all provided constraints. From this aspect, the selection process has the same conception as the optimization. Thus, the optimization model can be modified for the selection process such as supplier selection process, either material or logistics supplier. In addition, the optimization concept can be implemented in the delivery decisions such as delivery route, delivery mode and container size used as well.

For the simple problem like the selection of one alternative out of several available options is illustrated in case 5.2.1, delivery mode/ container size selection. It can be applied for the selection of the delivery mode, container size, or delivery route. But if each alternative also has sub–alternatives, for example, the selection of the freight forwarder, delivery route, or new supplier which each of them has different delivery choices under, case 5.2.2; the freight forwarder selection will be the representative of the problem. The application in other areas is possible with modification of the criteria used for determination and the conversion of these criteria to the concrete costs.

5.2.1 Delivery mode/container size selection (Model 3)

One vital decision made in the inbound logistics planning is the decision regarding the frequency of the delivery and delivery mode/ container size used for each supplier. In this case, the company has to trade-off between the delivery cost and other consequential costs such as inventory cost, delivery damage, and utilization percentage since they are normally conflict to each other.

In order to make a good decision, all related objectives, costs and constraints should be gathered. Similar to other logistics activities, the delivery mode selection aims to arrange the deliveries which meet the demand with the lowest total costs yet remaining the highest overall performances. Then non-monetary performances such as transit time and possible delay are converted into penalties to make them comparable with the delivery, inventory and damage cost. Therefore, the optimization model with these requirements is formulated as follow:

Objective function: $$MinTC = \sum z_i cc_i + \sum z_i n_i (t_i - t_{\min}) tc + \sum z_i n_i dd_i ic + \sum z_i n_i dm_i p + \sum z_i ic_i$$

Decision variables are: z_i

Subject to constraints:

$$z_i \geq 0$$

z_i = integer

$$\sum z_i n_i \geq \sum d$$

Where:

TC = Total costs which include transportation cost, delivery time penalty, delay penalty, damage penalty, and inventory cost

z_i = number of container for delivery mode i

cc_i = delivery cost of delivery mode i

n_i = number of pallet delivered at a time of delivery mode/container size i

t_i = delivery time of delivery mode i (day)

$t_{\min}$ = shortest delivery time of the available options except airfreight (day)

Or target delivery time (day)

tc = time penalty cost per day (can be inventory holding cost per day (ic) of materials from this supplier plus other opportunity lost cost)

dd_i = possible or average delay time of delivery mode i

ic = delay penalty cost (assume that it is the inventory cost per day as it causes more safety stock for the uncertainty)

dm_i = percentage of the transportation damage caused by delivery mode i

p = material cost per pallet

ic_i = inventory cost of deliver mode i

$\sum d$ = Total demand (number of pallet required)

The objective function is to minimize the total cost which contains delivery cost ($\sum z_i cc_i$), delivery time (longer transit time) penalty ($\sum z_i n_i (t_i - t_{\min}) tc$), delay penalty ($\sum z_i n_i dd_i ic$), damage penalty ($\sum z_i n_i dm_i p$), and inventory cost ($\sum z_i ic_i$).The constraints are the number of container which must be integer and greater than or equal to zero. Besides, the total number of pallets accumulated from all delivery modes must be greater than or equal to number of pallets required for production. This number of requirement normally comes from the company's budget if this calculation is done for the strategic inventory management and planning. Moreover, weekly or monthly demand can be gained from SAP, if the calculation is done for the operational delivery planning.

Below is the example data of the delivery cost and delivery performance in each delivery mode (i) of freight forwarder A:

Table 5 Cost and Performance of freight forwarder A for delivery mode selection

Delivery mode (i)	Delivery qty (pallet)	Delivery cost per pallet (USD)	Transit time (day)	Delay (day)	Delivery damage	Inventory cost (USD)
Air	1	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
LCL	1	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
20' container	10	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
40' container	20	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Note: Values in the dark blue cells are covered for the confidentiality reason

The required delivery quantity is 256 pallets

Formulate the Solver in Microsoft Excel according to the formulations and input data provided above and run the program to find the optimal value of z_i. This case study is formulated and demonstrated in Appendix 10.3.

Please note that the restriction of MOQ and full-pallet is omitted in this model in order to reduce the complication. This calculation uses the average value which may cause trivial difference in the actual inventory cost. In summary, the result will give the general idea how often and which delivery mode will suit the demand pattern at the lowest cost. The exact shipment arrangement and cost is discussed in the container loading optimization.

5.2.2 Freight forwarder selection (Model 4)

For the freight forwarder selection process, the company normally has the specification and criteria for the evaluation. Once the other specifications are met, the decision likely to prioritize on the delivery cost.

As stated in the delivery mode selection that the delivery cost is the tangible and the biggest cost in the inbound logistics. However, the other costs and performance should not be disregarded either. These hidden costs can cause the overall cost of the cheap alternative become greater than the initially expensive one. Therefore, the freight forwarder selection process should be considered including all possible costs occurred by the poor performance service in the calculation. Moreover, the optimization model must be used to find the best freight forwarder's alternative which really gives the lowest overall cost and contains the best overall performances bounded by the subjective function to meet the certain requirement.

The formulation will be fairly similar to the optimization model for the delivery mode selection but has the addition of the auxiliary variable b_j where the decision variable z_{ij} is in order to make the "either or" circumstance. Subsequently, the optimization model for the freight forwarder selection can be formulated as in the following equation.

Objective function:

$$MinTC = \sum b_j z_{ij} cc_{ij} + \sum b_j z_{ij} n_i (t_{ij} - t_{\min}) tc + \sum b_j z_{ij} n_i dd_{ij} ic + \sum b_j z_{ij} n_i dm_{ij} p + \sum b_j z_{ij} ic_i$$

Decision variables are: b_j and z_{ij}

Subject to constraints:

b_j = integer

b_j = binary

$b_j \geq 0$

$\sum b_j \leq 1$

$z_{ij} \geq 0$

z_{ij} = integer

$\sum b_j z_{ij} n_i \geq \sum d$

Where:

TC = Total costs which include transportation cost, delivery time penalty, delay penalty, damage penalty, and inventory cost

b_j = decision on supplier j, 1 if supplier j is selected, 0 otherwise.

z_{ij} = number of container for delivery mode I of supplier j

cc_{ij} = delivery cost in delivery mode I of supplier j

n_i = number of pallet delivered at a time of delivery mode/container size i

t_{ij} = delivery time in delivery mode i (day) of supplier j

$t_{\min}$ = shortest delivery time of the available options except airfreight (day)

Or target delivery time (day)

tc = time penalty cost per day (can be inventory holding cost per day (ic) of materials from this supplier plus other opportunity lost cost)

dd_{ij} = possible or average delay time in delivery mode I of supplier j

ic = delay penalty cost (assume that it is the inventory cost per day as it causes more safety stock for the uncertainty)

dm_{ij} = transportation damage (%) caused by delivery mode i of supplier j

p = material cost per pallet

ic_i = inventory cost of deliver mode i

$\sum d$ = Total demand (number of pallet required)

Use the same input of freight forwarder, Table 6, from the previous case in this scenario and add the input of another alternative in to compete with.

Input of freight forwarder B

Table 6 Cost and Performance of freight forwarder B for freight forwarder selection

Delivery mode	Delivery qty (pallet)	Delivery cost per pallet (USD)	Delivery time (day)	Delay (day)	Delivery damage	Inventory cost (USD)
Air	1	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
LCL	1	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
20' container	10	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
40' container	20	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Note: Values in the dark blue cells are covered for the confidentiality reason

Put all these formulations and data in the Solver and run the optimization to find b_j and z_{ij} which give the minimum total costs. Appendix 10.4 illustrates the model programmed in MS Excel Solver.

6. Results and Analysis

As the methods shown in applied solution procedure, the results will be as follows.

6.1 Case study 1: The delivery planning optimization

6.1.1 Delivery choices optimization: with fixed loading pattern for the roll materials (Model 1)

z_i : Number of container for pattern i (i = x1, x2, …) during week 0930-0933

Table 7 Result comparison between the current method and Model 1

By	Zi	wk30	wk31	wk32	wk33
Current method	X1				
	X2	1			
	X3			1*	
	X4				
Suggested method	X1				
	X2				
	X3	1			
	X4				

*Note: The order in week 32 has not been issued at the time being. But there is a shortage of one material that can be slit from pattern X3 only. Consequently, it is assumed that the shortage will trigger the order of one container of pattern X3 in that week.

Thus, the total costs are as in Table 8.

Table 8 Total cost of Model 1

	Week	wk30	wk31	wk32	wk33	Total
Current method	**Total cost**	184 180		248 369		433 549
	Slitting waste (USD)	3 283		4 182		7 465
	Container loading waste(USD)	774		685		1 459
	Material cost (USD)	174 567		240 131		414 698
	Inventory holding cost (USD)	2 699		514		3 213
	Delivery cost (USD)	2 857		2 857		5 714
	Processing time (min)	30		30		60
Model 1	**Total cost**	250 931				250 931
	Slitting waste (USD)	4 182				4 182
	Container loading waste(USD)	685				685
	Material cost (USD)	240 131				240 131
	Inventory holding cost (USD)	3 077				3 077
	Delivery cost (USD)	2 857				2 857
	Processing time (min)	15				15

All constraints are met in both scenarios; however, there are differences between two methods. The current method tends to request for the order as soon as the inventory reaches the reorder point. Also, it will select the pattern providing material which is needed in that week or the week after. However, there is the possibility that the selected pattern is not the most beneficial in the longer time frame. Moreover, the safety stock set in the current method is the constant number which is used as the reorder point. Consequently, it has less freedom comparing to the safety stock range used in the optimization solver which allows more candidates to balance stock of all materials and minimize overall cost.

6.1.2 Container loading optimization – material on pallet (Model 2)

As mentioned above that there are two types of procurement for pallet loaded material, full-pallet purchase and not full-pallet purchase, the optimization models provide result as in Table 9.

Table 9 Cost comparison between different safety stock level and different cases of pallet loaded material (Model 2)

Cost (USD)	Actual: 100% Safety Stock & not full-pallet	Full –pallet (case A)		Not full-pallet (case B)	
		80-120% Safety Stock	100-120% Safety Stock	80-120% Safety Stock	100-120% Safety Stock
Total Cost	475 160.62	412 713.95	495 231.86	351 920.36	416 875.71
Material Cost	455 898.41	397 419.36	475 823.59	337 188.45	398 828.34
Inventory Cost	4 262.20	4 044.59	4 408.26	3 481.91	3 862.36
Transport Cost	15 000.00	11 250.00	15 000.00	11 250.00	14 185.00
No of container 20'/40'	0/4	0/3	0/4	0/3	1/3
Container utilization	86	100	100	100	100

The results of this optimization model are shorter ordering time, lowest cost order, and working standard. Presently, call-offs in an order are adjusted according to all constraints by a material planner depending on his experience. Consequently, the optimal solution within all constraints may not be gained accidentally and the current working time is high and unpredictable. For example, safety stocks of some materials do not meet the desirable level. On the other hand, by using this model, around 15 minutes can be saved comparing with time spent in the current work. Moreover, 100% container utilization is gained definitely. Also, the safety stock level can be determined as a range contrasting the safety stock in the current system which is fixed. Thus, the model allows call-offs to be in the acceptable range which the entire restrictions are considered. Finally, the lowest cost is obtained undoubtedly because of Solver's property, minimizing the total cost.

As the result in Table 9, the total cost of actual order which is not full-pallet type is higher than the total cost of 100-120% safety stock of case B. This can prove that the model provides the lower cost under the same constraint. In addition, comparison of two optimal solutions, the cost of case A is more expensive than the cost of case B with the same safety stock level owing to the difference of the cheapest item's amount.

Table 10 Cost comparison between the current method and the new model (Model 2 case B)

Cost (USD)	Actual			Not full-pallet (case B) 100-120% SS			
	W12-15	W16-20	W21-24	W12	W13-17	W18-23	W24
Total Cost	207 469.31	142 875.99	124 815.31	112 738.30	113 034.55	131 937.19	59 165.65
Material Cost	198 621.85	137 471.48	119 805.08	108 669.66	107 725.41	126 451.08	55 982.19
Inventory Cost	1 347.46	1 654.51	1 260.23	318.64	1 559.14	1 736.12	248.46
Transport Cost	7 500.00	3 750.00	3 750.00	3 750.00	3 750.00	3 750.00	2 935.00
No of container 20'/40'	0/2	0/1	0/1	0/1	0/1	0/1	1/0
Container utilization	100	0.94	0.78	100	100	100	100

Table 10 expresses that the new model provides the lower total cost under the same constraints. Even there is one delivery time of the new model more than the delivery frequency of the current method; the total transport cost is lower because the appropriate container size can be chosen. As a result, the responsiveness is better by using the new model. Nevertheless, in the real delivery planning, the last delivery of the new model will not occur. The demand in week 24 will be combined with the following weeks in order to place a 40 feet container order. However, this table is created merely to compare the total cost under the same time period.

6.2 Case study 2: The alternative selection

6.2.1 Delivery mode/container size selection (Model 3)

After inputs data from Table 5 in the optimization Model 3 to calculate the total cost and choose the delivery mode which gives the least cost, the result is as in Table 11.

Table 11 Result of Model 3: Delivery mode selection

Mode (i)	Container	Delivery qty (pallet)	Delivery cost (USD)	Time penalty (USD)	Delay cost (USD)	Damage cost (USD)	Inventory cost (USD)	Total cost (USD)
	z_i	n_i	$z_i cc_i$	$z_i n_i (t_i - t_{min}) tc$	$z_i n_i dd_i ic$	$z_i n_i dm_i p$	$z_i ic_i u_i$	
Air	0	1	0	0	0	0	0	0
LCL	0	1	0	0	0	0	0	0
20' cont	0	10	0	0	0	0	0	0
40' cont	13	20	48 750	0	277	18 170	2 926	70 124
		260	48 750	0	277	18 170	2 926	70 124

Utilization = 98%

The solution goes to i = 40' container because this delivery mode spends the lowest delivery cost per pallet, shortest transit time, and best delivery reliability. Although the high number of pallet per delivery (20 pallets) causes high inventory at the factory, the consumption rate is high enough to make the inventory cost lower than the other accumulated costs. However, if the cost, performance, and demand are changed, the solution will be changed as well. Consequently, if there is dramatic change in any of those factors, the manager should update the input and review the selection.

6.2.2 Freight forwarder selection (Model 4)

With the addition of the auxiliary variable b_j, the optimization model will select value 1 for the alternative that gives the minimum cost and 0 for the one that gives the higher cost.

Result from the optimization, is as follow

Table 12 Result of freight forwarder selection by using Model 4

	j = A	Binary	Container	Delivery qty (pallet)	Delivery cost (USD)	Time penalty (USD)	Delay cost (USD)	Damage cost (USD)	Inventory cost (USD)	Total cost (USD)
	Mode (i)	b_j	z_{ij}	n_i	$b_j z_{ij} cc_{ij}$	$b_j z_{ij} n_i (t_i - t_{min}) tc$	$b_j z_{ij} n_i d d_{ij} ic$	$b_j z_{ij} n_i dm_{ij} p$	$b_j z_{ij} ic_i u_{ij}$	
j = A	Total Cost			0	0	0	0	0	0	0
	Air	0	0.0	1	0	0	0	0	0	0
	LCL	0	0.0	1	0	0	0	0	0	0
	20'	0	0.0	10	0	0	0	0	0	0
	40'	0	0.0	20	0	0	0	0	0	0
j = B	Total cost			260	39 000	277	554	18 170	2 976	60 978
	Air	1	0.0	1	0	0	0	0	0	0
	LCL	1	0.0	1	0	0	0	0	0	0
	20'	1	0.0	10	0	0	0	0	0	0
	40'	1	13.0	20	39 000	277	554	18 170	2 976	60 978

Utilization = 98%

The cheapest delivery arrangement for 256 pallets of freight forwarder A is 13 containers of 40’ container which equals to 70 124 USD while the cheapest delivery arrangement of freight forwarder B is 13 containers of 40’ container as well but it gives the lower cost, 60 978 USD. Therefore, the freight forwarder B is selected to handle shipments from this origin.

In summary, all models express that the lower safety stock level creates the lower total cost. Besides, the purchasing agreements which are pallet loaded and slitting and loading pattern can affect on the total cost significantly. Due to ordering amount increases, then inventory cost and material cost arise accordingly.

All in all, the optimization can reduce the processing time as the optimal result is determined automatically without trial and error to find the better choice. Also, the optimal solution is assured that the result calculated by whoever will always be the same. That means the efficiency will not depend so much on the working experience or mathematics skill.

7. Discussion

There are two aspects to be noticed in this reports which are

7.1 Optimization

7.1.1 Boundary of the constraints

The narrow range of the constraints may cause difficulties in calculation and result in the infeasible solution. The potential problem will be the restriction to have integer number for the solution while having low and narrow range of safety stock. For example, the number of container required for each pattern may conflict with the required safety stock in the case that the designed patterns have different proportion of the slit width from the demand in that period. Therefore, the user may need to adjust the safety stock constraints boundary to be wider enough to allow the manipulation possible.

Moreover, the optimal result quality depends on the constraints of the model. In case 4.1.1, for instance, if the pattern is not optimal, the optimization is just an attempt to get the best option out of the existing pattern.

7.1.2 Limitation of Solver

Even Solver is a user-friendly program; however, there are three main problems resulting difficulties in optimization. First of all, problems contain mostly linear relationships but a few nonlinear relationships, IF and CHOOSE function, for instance, are not solved easily [23].

In addition, there is always limitation of variables and constraints numbers. For example, only 200 decision variables and 100 constraint cells of non-linear models are allowed for the standard Microsoft Excel Solver [24]. Furthermore, integer variables problem is needed longer execution time. Due to several combinations of specific integer value test is required, the memory and solution time may increase exponentially [24]. Thus, the model should be adjusted to be close to a linear problem leading the model solved effortlessly. Also, ingenious models can solve liner programming problems with hundreds of variables. Additionally, more powerful program such as Premium Solver can be used to determine complex optimization solution [25].

7.2 Company's constraints

7.2.1 Master roll width and slitting & loading pattern

Even the master roll width and slitting & loading patter are designed optimally already, however, if the volumes used for pattern design are different from the actual volume happens in the considering time frame, it may results in the under supply for some materials and over supply to the others. Consequently, the decision on the master roll slit width and slitting and loading pattern are the important mission for the company and the supplier to optimize with consideration of the fluctuation of demand effect.

Because of the demand fluctuation, however, the average demand which is used for the slitting and loading pattern design and the master roll width size decision may not be correct in some planning period resulting in the shortage of some materials and overstock of the others. Therefore, the optimization concept with advanced mathematical programming may be needed to find the optimal master roll width and slitting and loading pattern that is suitable for all time period, or various solutions for different level of demand.

7.2.2 Safety stock

According to minimize logistics cost model, safety stock level is an important parameter affecting the total cost. Not only forecast error is used to determine safety stock level, but also three supplier performances, delay (T), volume incompleteness (V), and quality (Q) should be taken into consideration as well. However, the appropriate volume is crucial as the excessive safety stock creates unnecessary high costs. Safety stock reduction can be achieved by decreasing forecast error. Also, related information, three performance and inventory, for instance, should be updated to respond to the current situation. Therefore, data collection and analysis are keys to set the proper safety stock level in order to cover all uncertainty, yet respecting the minimized cost.

7.2.3 MOQ and full-pallet order

Other important factors influencing the total cost are MOQ and full-pallet order agreement. For example, if the required amount of an item, in pallet, is 0.2 while MOQ is 0.6 and the order is needed to be a whole number, the ordering amount of the item is 1 unavoidably. In consequence, the company must spend surplus cost to meet all agreements which sometimes it is very costly, especially when the fractional part of MOQ is very small such as 1.01. Therefore, appropriate MOQ and loading restriction should be concerned before making an agreement with a supplier.

Even not full-pallet purchase can save the total cost significantly; however, it can cause extra expense and several problems in warehouse operations. As a result, the company must trade-off between warehouse management cost and material/inventory cost. Also, increasing one container in an order creates a dramatic logistics cost because of material cost, inventory cost, and transport cost. Thus, all parameters must be determined circumspectly in order to lead the company reaches the highest profit.

7.2.4 Cost calculation

The delivery cost and inventory cost are the tangible costs but the rest costs used in these models are the hidden costs which are normally neglected in the traditional comparison. In order to gain the real optimal solution regarding all possible costs, these hidden costs should be included. This notion not only intends to reflect the real costs but also emphasizes the attempt to optimize the overall logistics performances which are the delivery cost, time, quality (delay & damage), and utilization by converting them into the form of cost which is tangible and comparable.

The effectiveness of the calculation relatively depends on the accuracy of the inventory handling cost, time penalties and performance measurement. As for now, there are not any prices set and historical performance measurement record has not been kept systematically. Hence, the inventory cost per unit, penalties and performance values used in this calculation is just the estimation. For the practical use, the company has to discuss within supply chain team to find the appropriate and reasonable values. Thus, the reliability and validity of the input data should be assessed and updated before using.

8. Conclusions & recommendations

8.1 Conclusion

Because the current tool, SAP, executes material requirement planning with singular item basis while the overseas shipment combines all materials of the same supplier together; the extra and manual calculation has to be done in the spreadsheet by the material planners to plan the delivery that has the least cost and meets required inventory level. To ensure the efficiency of the process, the standard optimization tools for delivery planning are developed in this paper. Model 1 is utilized for planning the delivery of the rolled materials which have the fixed slitting and loading pattern. Model 2 is created for the delivery planning of pallet loaded materials regarding 2 different conditions, case A which is the full pallet restriction is considered and case B which is contrarily. The results illustrate that the optimization models provide the optimal solutions which have lower total costs and require less processing time than the current method.

In addition, due to the current market condition increasing the significance of 4 major logistics performances which are the delivery time, delivery cost, delivery quality, and delivery utilization; the supply chain and logistics functions need to achieve all performances with the minimum total cost. The alternative selection process which combines the total logistics costs, performance measurement, and systems optimization concept altogether is constructed to ensure the optimal decision making in the logistics operations. The conversion of some performance measurements such as the delivery time and delay time into penalties is generated. Model 3 is designed accordingly to select the delivery mode which gives the minimum overall logistics cost. Model 4 extends the use of Model 3 by adding auxiliary binary variables to select the appropriate freight forwarder to handle the operations in the route. The new approach will be expected to give the ensured optimal solution and increase the transparency of the decision making if it is used as the standard procedure.

Generally, the optimization tools in this paper are developed with the intention to optimize the overall logistics cost including the intangible costs. Furthermore, desired objectives have been considered and converted into costs for comparison and all related information from every function in the supply chain has been shared to create the process alignment and gain better communications which are the important characteristics of the responsive supply chain.

8.2 Recommendation

Currently, inbound logistics has not been measured regularly and systematically yet; but there are some records of the previous shipments. In consequence, performance measurement system for inbound logistics should be created. Also, the bottleneck and the hidden cost should be shown and analyzed the cause of problems.

In this paper, the selection of the logistics supplier is picked as an example of the case. It can be modified for use in the material supplier selection or other types of selection as it has the same concept, just different criteria and related costs.

Currently, the decision making for the freight forwarder has been made based on cost of 40’ container only. Since the actual deliveries can be arranged with other delivery mode, the consideration on all possible modes will grant more accuracy.

At present, the other performance measurements except the delivery cost are not taken into account yet. By including all aspects and hidden costs, the comparison will be fairer and more precise.

The optimization models show that related parameters such as MOQ affect on the total logistics cost. Thus, the parameters ought to be reviewed in order to get the optimal value.

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10. Appendices

Note: Dark blue cells are covered for confidentiality reason.

10.1 Model 1: Pattern selection: Fixed slitting and loading pattern

	A	B	C	D	E
1	**Optimization for fixed slitting and loading pattern**				
2	**Basic data:**				
6	Unit :	rick			
7	Master roll width =	[redacted]	inches		
8	Material price =	[redacted]	USD/M2		
9	Loading length =	[redacted]	inches		
10	Delivery cost =	[redacted]	USD/40'container*		
11	Delivery waste =	[redacted]	USD/inch*		
13	Inventory holding cost =	[redacted]	USD/rick*		
14			* Note: Estimated cost		
20	**Slitting + Loading Pattern:**				
21	**Material \ Pattern**	**X1**	**X2**	**X3**	**X4**
22	1	6.0	3.0	3.0	
23	2				
24	3				
25	4			3.0	
26	5		2.0		4.0
27	6				
28	7		2.0		4.0
29	8			5.0	2.0
30	9				
31	10			2.0	2.0
32	11	2.0		2.0	4.0
33	12	6.0	3.0	3.0	
34	13	6.0	8.0	9.0	4.0
35	14		3.0	3.0	
36	15	2.0			2.0
37	No. of container	[redacted]	[redacted]	[redacted]	[redacted]
38	Slitting waste (M2)	[redacted]	[redacted]	[redacted]	[redacted]
39	Loading waste (inch)	[redacted]	[redacted]	[redacted]	[redacted]

Figure A 1 Solver of Model 1 (1)

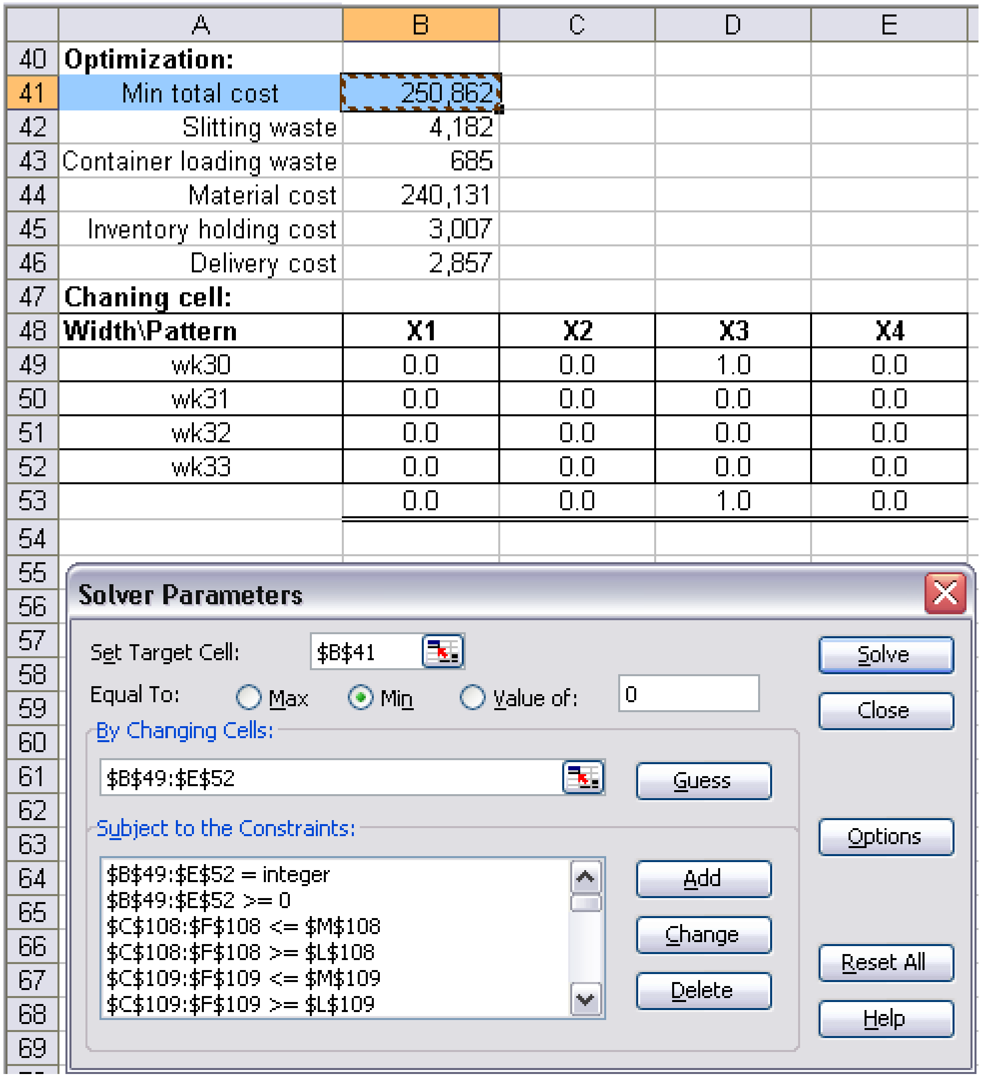


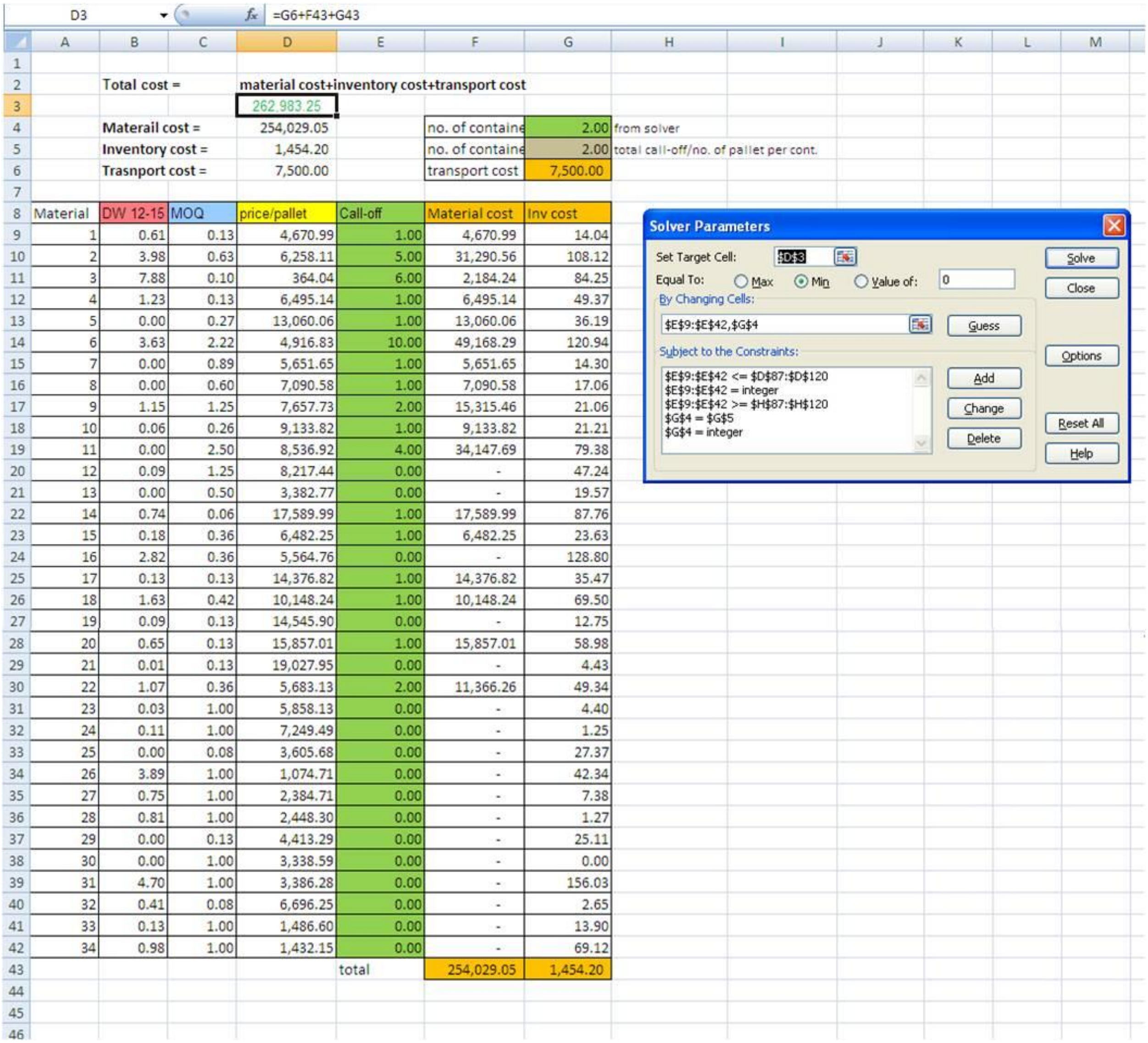
Figure A 2 Solver of Model 1 (2)

	A	B	C	D	E	F	K	L	M
71	**MRP:**								
72	**Supply**	**ice per ri**	**wk30**	**wk31**	**wk32**	**wk33**			
73	1	2,851	3.0	0.0	0.0	0.0			
74	2	3,374	0.0	0.0	0.0	0.0			
75	3	4,304	0.0	0.0	0.0	0.0			
76	4	4,995	3.0	0.0	0.0	0.0			
77	5	5,457	0.0	0.0	0.0	0.0			
78	6	5,664	0.0	0.0	0.0	0.0			
79	7	6,496	0.0	0.0	0.0	0.0			
80	8	6,774	5.0	0.0	0.0	0.0			
81	9	6,981	0.0	0.0	0.0	0.0			
82	10	7,318	2.0	0.0	0.0	0.0			
83	11	7,948	2.0	0.0	0.0	0.0			
84	12	9,141	3.0	0.0	0.0	0.0			
85	13	10,086	9.0	0.0	0.0	0.0			
86	14	11,332	3.0	0.0	0.0	0.0			
87	15	13,954	0.0	0.0	0.0	0.0			
88	Material cost		240,131	0	0	0			
89									
90	**Demand**	**Avg**	**wk30**	**wk31**	**wk32**	**wk33**			
91	1	0.5	0.6	0.4	0.2	0.6			
92	2	0.1	0.2	0.1	0.2	0.1			
93	3	0.4	0.6	0.4	0.3	0.2			
94	4	0.6	1.0	0.3	0.4	0.5			
95	5	0.0	0.0	0.0	0.0	0.0			
96	6	1.0	1.5	0.5	1.4	0.4			
97	7	0.6	0.8	0.5	0.7	0.3			
98	8	0.0	0.0	0.0	0.0	0.0			
99	9	0.1	0.2	0.1	0.1	0.1			
100	10	0.0	0.0	0.0	0.0	0.0			
101	11	0.3	0.3	0.2	0.6	0.2			
102	12	0.0	0.0	0.0	0.0	0.0			
103	13	1.8	2.6	1.2	2.3	1.1			
104	14	0.1	0.0	0.0	0.4	0.0			
105	15	0.2	0.2	0.1	0.4	0.1			
106							**Constraints:**		
107	**Inventory**	**wk29**	**wk30**	**wk31**	**wk32**	**wk33**		**>=Min**	**<=Max**
108	1	4.7	7.1	6.7	6.5	5.9		1.4	45.6
109	2	2.9	2.8	2.6	2.5	2.4		0.4	14.0
110	3	8.3	7.7	7.3	7.0	6.8		1.1	38.2
111	4	3.0	5.1	4.8	4.3	3.8		1.7	55.1
112	5	13.1	13.1	13.1	13.1	13.1		0.0	15.0
113	6	9.2	7.7	7.2	5.8	5.4		2.9	96.0
114	7	10.1	9.3	8.8	8.1	7.8		1.7	56.2
115	8	0.0	5.0	5.0	5.0	5.0		0.0	5.0
116	9	1.4	1.2	1.1	1.0	0.9		0.4	11.7
117	10	0.0	2.0	2.0	2.0	2.0		0.0	5.0
118	11	5.4	7.1	7.0	6.3	6.1		1.0	33.5
119	12	0.1	3.1	3.1	3.1	3.1		0.0	5.0
120	13	4.0	10.4	9.2	6.9	5.8		5.4	179.6
121	14	7.8	10.8	10.8	10.5	10.5		0.3	11.5
122	15	2.8	2.6	2.5	2.1	2.0		0.6	20.6
123	Holding cost	625	814	782	721	690			

Figure A 3 Solver of Model 1 (3)

10.2 Model 2: Container loading optimization – material on pallet

Case A



D3 =G6+F43+G43

Total cost =	material cost+inventory cost+transport cost
	262,983.25
Materail cost =	254,029.05
Inventory cost =	1,454.20
Trasnport cost =	7,500.00

no. of containe	2.00	from solver
no. of containe	2.00	total call-off/no. of pallet per cont.
transport cost	7,500.00	

Material	DW 12-15	MOQ	price/pallet	Call-off	Material cost	Inv cost
1	0.61	0.13	4,670.99	1.00	4,670.99	14.04
2	3.98	0.63	6,258.11	5.00	31,290.56	108.12
3	7.88	0.10	364.04	6.00	2,184.24	84.25
4	1.23	0.13	6,495.14	1.00	6,495.14	49.37
5	0.00	0.27	13,060.06	1.00	13,060.06	36.19
6	3.63	2.22	4,916.83	10.00	49,168.29	120.94
7	0.00	0.89	5,651.65	1.00	5,651.65	14.30
8	0.00	0.60	7,090.58	1.00	7,090.58	17.06
9	1.15	1.25	7,657.73	2.00	15,315.46	21.06
10	0.06	0.26	9,133.82	1.00	9,133.82	21.21
11	0.00	2.50	8,536.92	4.00	34,147.69	79.38
12	0.09	1.25	8,217.44	0.00	-	47.24
13	0.00	0.50	3,382.77	0.00	-	19.57
14	0.74	0.06	17,589.99	1.00	17,589.99	87.76
15	0.18	0.36	6,482.25	1.00	6,482.25	23.63
16	2.82	0.36	5,564.76	0.00	-	128.80
17	0.13	0.13	14,376.82	1.00	14,376.82	35.47
18	1.63	0.42	10,148.24	1.00	10,148.24	69.50
19	0.09	0.13	14,545.90	0.00	-	12.75
20	0.65	0.13	15,857.01	1.00	15,857.01	58.98
21	0.01	0.13	19,027.95	0.00	-	4.43
22	1.07	0.36	5,683.13	2.00	11,366.26	49.34
23	0.03	1.00	5,858.13	0.00	-	4.40
24	0.11	1.00	7,249.49	0.00	-	1.25
25	0.00	0.08	3,605.68	0.00	-	27.37
26	3.89	1.00	1,074.71	0.00	-	42.34
27	0.75	1.00	2,384.71	0.00	-	7.38
28	0.81	1.00	2,448.30	0.00	-	1.27
29	0.00	0.13	4,413.29	0.00	-	25.11
30	0.00	1.00	3,338.59	0.00	-	0.00
31	4.70	1.00	3,386.28	0.00	-	156.03
32	0.41	0.08	6,696.25	0.00	-	2.65
33	0.13	1.00	1,486.60	0.00	-	13.90
34	0.98	1.00	1,432.15	0.00	-	69.12
				total	254,029.05	1,454.20

Figure A 4 Solver of Model 2-Case A(1)

Inventory (pallet)

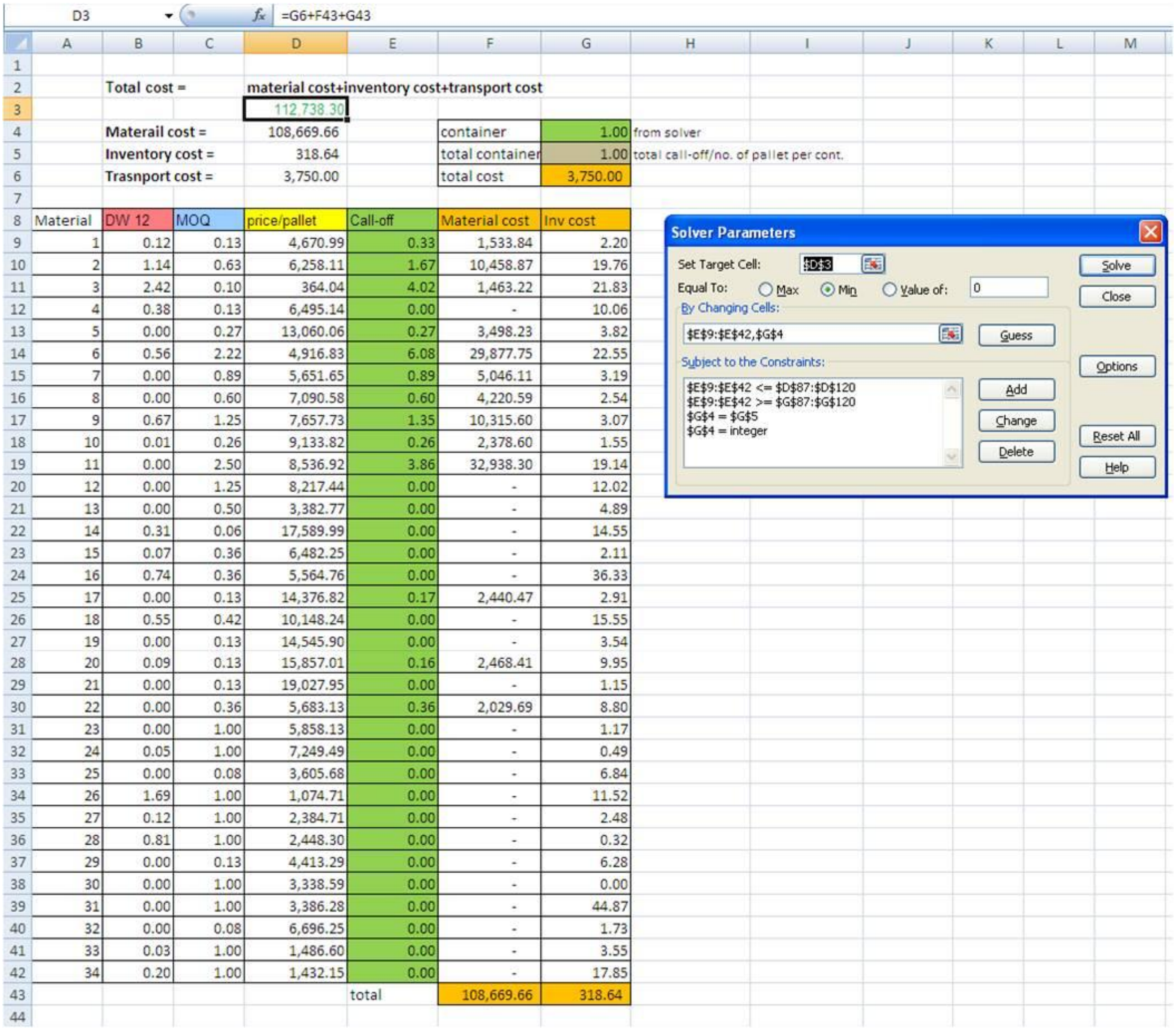
Material	Inv wk11	IW15	inv cost/pallet	inv cost	total	IW12	IW13	IW14	IW15
1	0.50	0.89	3.103	14.04	4.524	1.382	1.232	1.018	0.893
2	4.59	5.61	3.866	108.12	27.967	8.441	7.486	6.431	5.610
3	19.56	17.68	1.032	84.25	81.624	23.133	21.618	19.194	17.679
4	2.91	2.68	3.980	49.37	12.405	3.528	3.291	2.912	2.675
5	0.27	1.27	7.136	36.19	5.071	1.268	1.268	1.268	1.268
6	1.48	7.85	3.221	120.94	37.546	10.923	9.899	8.874	7.850
7	0.00	1.00	3.574	14.30	4.000	1.000	1.000	1.000	1.000
8	0.00	1.00	4.266	17.06	4.000	1.000	1.000	1.000	1.000
9	0.00	0.85	4.539	21.06	4.640	1.330	1.330	1.128	0.850
10	0.04	0.98	5.248	21.21	4.041	1.036	1.016	1.008	0.982
11	0.00	4.00	4.961	79.38	16.000	4.000	4.000	4.000	4.000
12	2.50	2.41	4.808	47.24	9.826	2.500	2.500	2.413	2.413
13	1.97	1.97	2.483	19.57	7.880	1.970	1.970	1.970	1.970
14	1.87	2.13	9.314	87.76	9.423	2.562	2.494	2.236	2.131
15	0.60	1.42	3.974	23.63	5.946	1.531	1.531	1.459	1.424
16	11.02	8.20	3.533	128.80	36.461	10.284	9.326	8.649	8.202
17	0.21	1.08	7.769	35.47	4.566	1.205	1.205	1.078	1.078
18	3.26	2.63	5.736	69.50	12.116	3.712	3.141	2.632	2.632
19	0.45	0.36	7.850	12.75	1.624	0.451	0.443	0.370	0.362
20	1.11	1.46	8.481	58.98	6.955	2.018	1.882	1.595	1.460
21	0.11	0.11	10.005	4.43	0.442	0.115	0.115	0.106	0.106
22	2.10	3.03	3.589	49.34	13.745	4.095	3.598	3.026	3.026
23	0.32	0.29	3.674	4.40	1.199	0.319	0.293	0.293	0.293
24	0.17	0.06	4.342	1.25	0.287	0.112	0.058	0.058	0.058
25	2.64	2.64	2.591	27.37	10.564	2.641	2.641	2.641	2.641
26	10.07	6.18	1.374	42.34	30.820	8.388	8.337	7.915	6.180
27	1.36	0.60	2.004	7.38	3.683	1.237	1.116	0.725	0.604
28	0.97	0.16	2.034	1.27	0.627	0.157	0.157	0.157	0.157
29	2.11	2.11	2.979	25.11	8.430	2.108	2.108	2.108	2.108
30	0.00	0.00	2.462	0.00	0.000	0.000	0.000	0.000	0.000
31	18.05	13.35	2.485	156.03	62.783	18.054	18.027	13.351	13.351
32	0.42	0.02	4.076	2.65	0.650	0.424	0.104	0.104	0.017
33	2.29	2.16	1.572	13.90	8.844	2.261	2.230	2.192	2.162
34	11.76	10.78	1.546	69.12	44.718	11.552	11.356	11.030	10.780
				1,454.20	483.41				

Figure A 5 Solver of Model 2- Case A (2)

	A	B	C	D	E	F	G	H	I
85		Max CO constraint			Min CO constraint				
86	Material	120	CO max	roundup max	100	CO min	roundup min	+ MOQ concerning	
87	1	0.71	0.82	1.000	0.59	0.70	1.00	1.00	
88	2	6.13	5.52	6.000	5.11	4.50	5.00	5.00	
89	3	21.15	9.47	10.000	17.63	5.95	6.00	6.00	
90	4	2.87	1.20	2.000	2.40	0.72	1.00	1.00	
91	5	0.46	0.19	1.000	0.38	0.11	1.00	1.00	
92	6	8.23	10.38	11.000	6.86	9.01	10.00	10.00	
93	7	1.02	1.02	2.000	0.85	0.85	1.00	1.00	
94	8	0.34	0.34	1.000	0.28	0.28	1.00	1.00	
95	9	0.81	1.96	2.000	0.68	1.83	2.00	2.00	
96	10	0.17	0.19	1.000	0.14	0.16	1.00	1.00	
97	11	4.63	4.63	5.000	3.86	3.86	4.00	4.00	
98	12	0.66	0.00	0.000	0.55	0.00	0.00	0.00	
99	13	0.72	0.00	0.000	0.60	0.00	0.00	0.00	
100	14	1.64	0.51	1.000	1.36	0.23	1.00	1.00	
101	15	0.55	0.13	1.000	0.46	0.04	1.00	1.00	
102	16	6.86	0.00	0.000	5.71	0.00	0.00	0.00	
103	17	0.45	0.37	1.000	0.38	0.30	1.00	1.00	
104	18	2.30	0.67	1.000	1.92	0.28	1.00	1.00	
105	19	0.31	0.00	0.000	0.26	0.00	0.00	0.00	
106	20	1.41	0.95	1.000	1.17	0.71	1.00	1.00	
107	21	0.00	0.00	0.000	0.00	0.00	0.00	0.00	
108	22	2.71	1.68	2.000	2.26	1.23	2.00	2.00	
109	23	0.00	0.00	0.000	0.00	0.00	0.00	0.00	
110	24	0.00	0.00	0.000	0.00	0.00	0.00	0.00	
111	25	0.00	0.00	0.000	0.00	0.00	0.00	0.00	
112	26	0.00	0.00	0.000	0.00	0.00	0.00	0.00	
113	27	0.00	0.00	0.000	0.00	0.00	0.00	0.00	
114	28	0.00	0.00	0.000	0.00	0.00	0.00	0.00	
115	29	0.00	0.00	0.000	0.00	0.00	0.00	0.00	
116	30	0.00	0.00	0.000	0.00	0.00	0.00	0.00	
117	31	0.00	0.00	0.000	0.00	0.00	0.00	0.00	
118	32	0.00	0.00	0.000	0.00	0.00	0.00	0.00	
119	33	0.68	0.00	0.000	0.57	0.00	0.00	0.00	
120	34	3.74	0.00	0.000	3.11	0.00	0.00	0.00	
121				49				40	total pallet
122				2.45				2.00	no.of container
123									
124									

Figure A 6 Solver of Model 2- Case A (3)

Case B



	Total cost =		material cost+inventory cost+transport cost			
			112,738.30			
	Materail cost =		108,669.66		container	1.00 from solver
	Inventory cost =		318.64		total container	1.00 total call-off/no. of pallet per cont.
	Trasnport cost =		3,750.00		total cost	3,750.00

Material	DW 12	MOQ	price/pallet	Call-off	Material cost	Inv cost
1	0.12	0.13	4,670.99	0.33	1,533.84	2.20
2	1.14	0.63	6,258.11	1.67	10,458.87	19.76
3	2.42	0.10	364.04	4.02	1,463.22	21.83
4	0.38	0.13	6,495.14	0.00	-	10.06
5	0.00	0.27	13,060.06	0.27	3,498.23	3.82
6	0.56	2.22	4,916.83	6.08	29,877.75	22.55
7	0.00	0.89	5,651.65	0.89	5,046.11	3.19
8	0.00	0.60	7,090.58	0.60	4,220.59	2.54
9	0.67	1.25	7,657.73	1.35	10,315.60	3.07
10	0.01	0.26	9,133.82	0.26	2,378.60	1.55
11	0.00	2.50	8,536.92	3.86	32,938.30	19.14
12	0.00	1.25	8,217.44	0.00	-	12.02
13	0.00	0.50	3,382.77	0.00	-	4.89
14	0.31	0.06	17,589.99	0.00	-	14.55
15	0.07	0.36	6,482.25	0.00	-	2.11
16	0.74	0.36	5,564.76	0.00	-	36.33
17	0.00	0.13	14,376.82	0.17	2,440.47	2.91
18	0.55	0.42	10,148.24	0.00	-	15.55
19	0.00	0.13	14,545.90	0.00	-	3.54
20	0.09	0.13	15,857.01	0.16	2,468.41	9.95
21	0.00	0.13	19,027.95	0.00	-	1.15
22	0.00	0.36	5,683.13	0.36	2,029.69	8.80
23	0.00	1.00	5,858.13	0.00	-	1.17
24	0.05	1.00	7,249.49	0.00	-	0.49
25	0.00	0.08	3,605.68	0.00	-	6.84
26	1.69	1.00	1,074.71	0.00	-	11.52
27	0.12	1.00	2,384.71	0.00	-	2.48
28	0.81	1.00	2,448.30	0.00	-	0.32
29	0.00	0.13	4,413.29	0.00	-	6.28
30	0.00	1.00	3,338.59	0.00	-	0.00
31	0.00	1.00	3,386.28	0.00	-	44.87
32	0.00	0.08	6,696.25	0.00	-	1.73
33	0.03	1.00	1,486.60	0.00	-	3.55
34	0.20	1.00	1,432.15	0.00	-	17.85
				total	108,669.66	318.64

Figure A 7 Solver of Model 2- Case B (1)

Inventory (pallet)

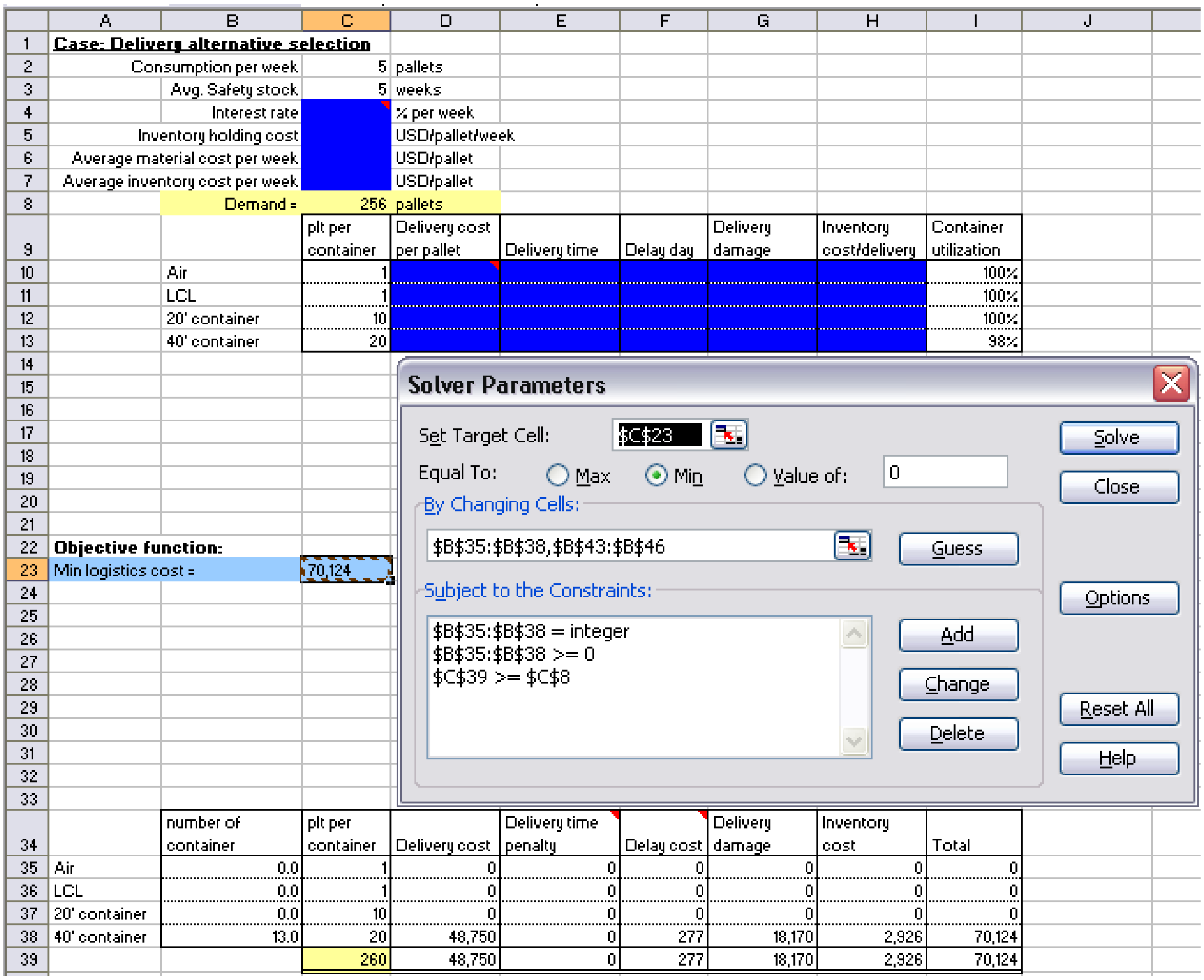
Material	Inv wk11	IW12	inv cost/pallet	inv cost	total	IW12
1	0.50	0.71	3.103	2.20	0.710	0.710
2	4.59	5.11	3.866	19.76	5.112	5.112
3	19.56	21.15	1.032	21.83	21.152	21.152
4	2.91	2.53	3.980	10.06	2.528	2.528
5	0.27	0.54	7.136	3.82	0.536	0.536
6	1.48	7.00	3.221	22.55	6.999	6.999
7	0.00	0.89	3.574	3.19	0.893	0.893
8	0.00	0.60	4.266	2.54	0.595	0.595
9	0.00	0.68	4.539	3.07	0.678	0.678
10	0.04	0.30	5.248	1.55	0.296	0.296
11	0.00	3.86	4.961	19.14	3.858	3.858
12	2.50	2.50	4.808	12.02	2.500	2.500
13	1.97	1.97	2.483	4.89	1.970	1.970
14	1.87	1.56	9.314	14.55	1.562	1.562
15	0.60	0.53	3.974	2.11	0.531	0.531
16	11.02	10.28	3.533	36.33	10.284	10.284
17	0.21	0.38	7.769	2.91	0.375	0.375
18	3.26	2.71	5.736	15.55	2.712	2.712
19	0.45	0.45	7.850	3.54	0.451	0.451
20	1.11	1.17	8.481	9.95	1.173	1.173
21	0.11	0.11	10.005	1.15	0.115	0.115
22	2.10	2.45	3.589	8.80	2.452	2.452
23	0.32	0.32	3.674	1.17	0.319	0.319
24	0.17	0.11	4.342	0.49	0.112	0.112
25	2.64	2.64	2.591	6.84	2.641	2.641
26	10.07	8.39	1.374	11.52	8.388	8.388
27	1.36	1.24	2.004	2.48	1.237	1.237
28	0.97	0.16	2.034	0.32	0.157	0.157
29	2.11	2.11	2.979	6.28	2.108	2.108
30	0.00	0.00	2.462	0.00	0.000	0.000
31	18.05	18.05	2.485	44.87	18.054	18.054
32	0.42	0.42	4.076	1.73	0.424	0.424
33	2.29	2.26	1.572	3.55	2.261	2.261
34	11.76	11.55	1.546	17.85	11.552	11.552
				318.64	114.73	

Figure A 8 Solver of Model 2- Case B (2)

	A	B	C	D	E	F	G	H
85		Max CO constraint			Min CO constraint			
86	Material	120	CO max	CO max+MOQ	100	CO min	+MOQ concerning	
87	1	0.71	0.33	0.328	0.59	0.21	0.21	
88	2	6.13	2.69	2.694	5.11	1.67	1.67	
89	3	21.15	4.02	4.019	17.63	0.49	0.49	
90	4	2.87	0.35	0.347	2.40	0.00	0.00	
91	5	0.46	0.19	0.268	0.38	0.11	0.27	
92	6	8.23	7.31	7.310	6.86	5.94	5.94	
93	7	1.02	1.02	1.022	0.85	0.85	0.89	
94	8	0.34	0.34	0.595	0.28	0.28	0.60	
95	9	0.81	1.48	1.483	0.68	1.35	1.35	
96	10	0.17	0.13	0.260	0.14	0.10	0.26	
97	11	4.63	4.63	4.630	3.86	3.86	3.86	
98	12	0.66	0.00	0.000	0.55	0.00	0.00	
99	13	0.72	0.00	0.000	0.60	0.00	0.00	
100	14	1.64	0.07	0.073	1.36	0.00	0.00	
101	15	0.55	0.02	0.357	0.46	0.00	0.00	
102	16	6.86	0.00	0.000	5.71	0.00	0.00	
103	17	0.45	0.24	0.245	0.38	0.17	0.17	
104	18	2.30	0.00	0.000	1.92	0.00	0.00	
105	19	0.31	0.00	0.000	0.26	0.00	0.00	
106	20	1.41	0.39	0.390	1.17	0.16	0.16	
107	21	0.00	0.00	0.000	0.00	0.00	0.00	
108	22	2.71	0.61	0.615	2.26	0.16	0.36	
109	23	0.00	0.00	0.000	0.00	0.00	0.00	
110	24	0.00	0.00	0.000	0.00	0.00	0.00	
111	25	0.00	0.00	0.000	0.00	0.00	0.00	
112	26	0.00	0.00	0.000	0.00	0.00	0.00	
113	27	0.00	0.00	0.000	0.00	0.00	0.00	
114	28	0.00	0.00	0.000	0.00	0.00	0.00	
115	29	0.00	0.00	0.000	0.00	0.00	0.00	
116	30	0.00	0.00	0.000	0.00	0.00	0.00	
117	31	0.00	0.00	0.000	0.00	0.00	0.00	
118	32	0.00	0.00	0.000	0.00	0.00	0.00	
119	33	0.68	0.00	0.000	0.57	0.00	0.00	
120	34	3.74	0.00	0.000	3.11	0.00	0.00	
121				25			16	total pallet
122				1.23			0.81	no.of container

Figure A 9 Solver of Model 2- Case B (3)

10.3 Model 3: Delivery alternative selection



	A	B	C	D	E	F	G	H	I
1	Case: Delivery alternative selection								
2		Consumption per week	5	pallets					
3		Avg. Safety stock	5	weeks					
4		Interest rate		% per week					
5		Inventory holding cost		USD/pallet/week					
6		Average material cost per week		USD/pallet					
7		Average inventory cost per week		USD/pallet					
8		Demand =	256	pallets					
9			plt per container	Delivery cost per pallet	Delivery time	Delay day	Delivery damage	Inventory cost/delivery	Container utilization
10		Air	1						100%
11		LCL	1						100%
12		20' container	10						100%
13		40' container	20						98%
22	Objective function:								
23	Min logistics cost =		70,124						

	A	B	C	D	E	F	G	H	I
34		number of container	plt per container	Delivery cost	Delivery time penalty	Delay cost	Delivery damage	Inventory cost	Total
35	Air	0.0	1	0	0	0	0	0	0
36	LCL	0.0	1	0	0	0	0	0	0
37	20' container	0.0	10	0	0	0	0	0	0
38	40' container	13.0	20	48,750	0	277	18,170	2,926	70,124
39			260	48,750	0	277	18,170	2,926	70,124

Figure A 10 Solver of Model 3

10.4 Model 4: Freight Forwarder Selection with alternative selection

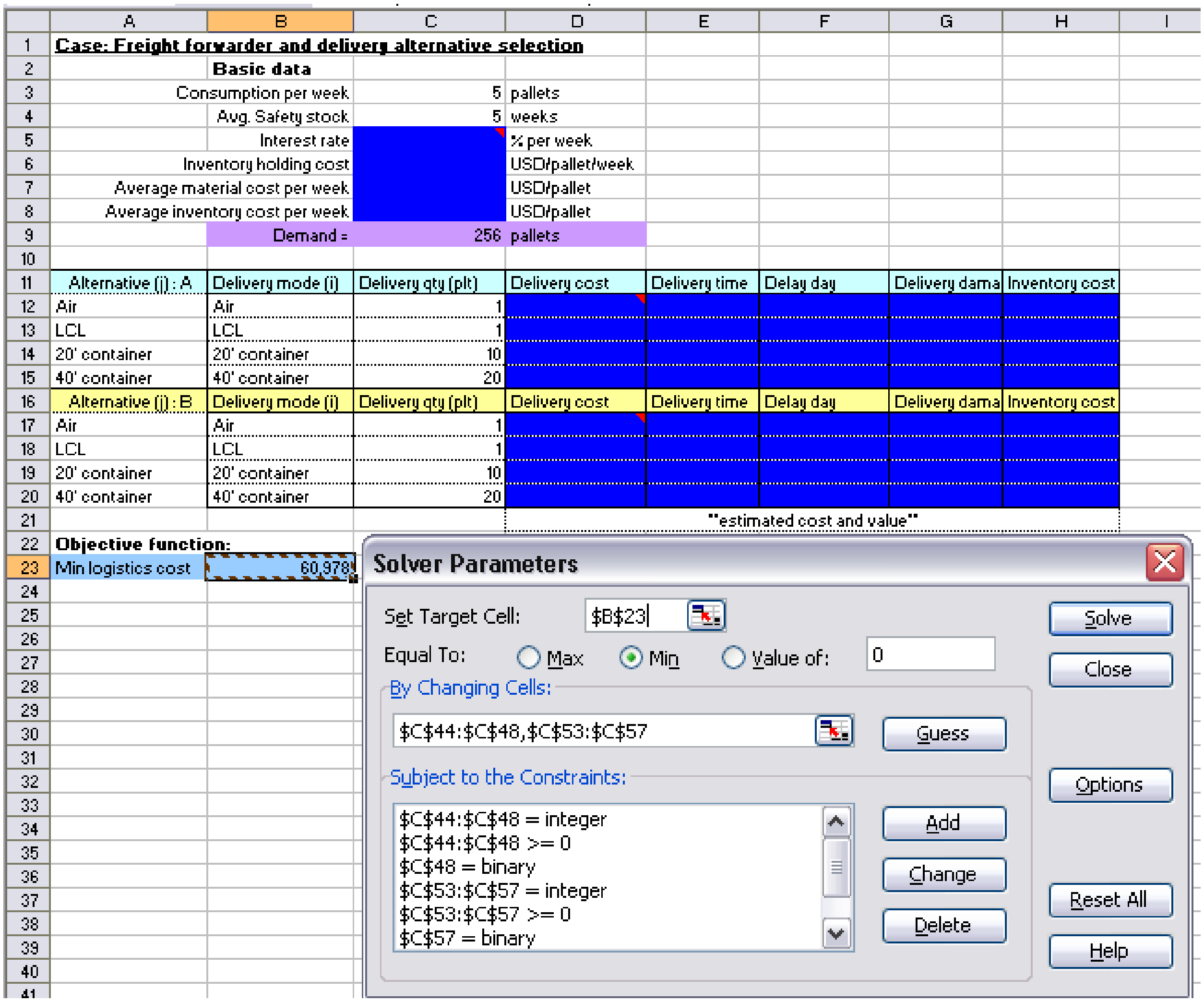
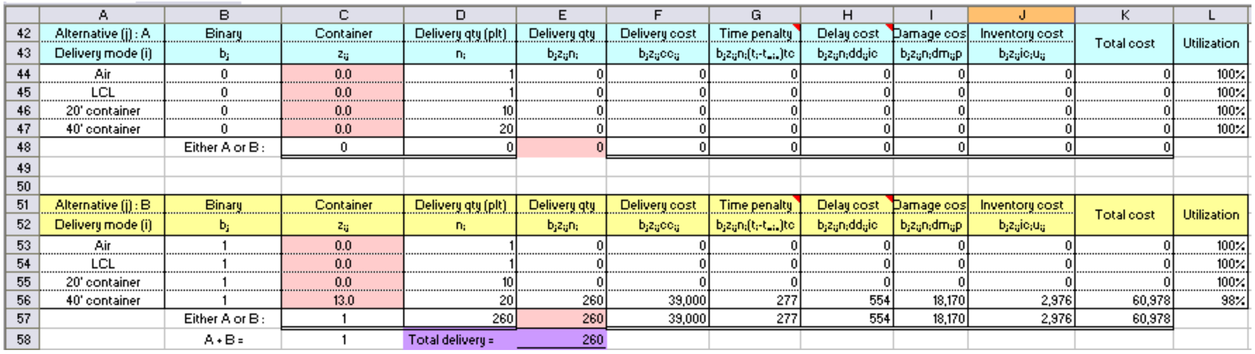


Figure A 11 Solver of Model 4 (1)



	A	B	C	D	E	F	G	H	I	J	K	L
42	Alternative (j) : A	Binary	Container	Delivery qty (plt)	Delivery qty	Delivery cost	Time penalty	Delay cost	Damage cos	Inventory cost	Total cost	Utilization
43	Delivery mode (i)	b_j	z_{ij}	n_i	$b_jz_{ij}n_i$	$b_jz_{ij}cc_{ij}$	$b_jz_{ij}n_i(t_i-t_{min})tc$	$b_jz_{ij}n_idd_{ij}ic$	$b_jz_{ij}n_idm_{ij}p$	$b_jz_{ij}ic_iu_{ij}$		
44	Air	0	0.0	1	0	0	0	0	0	0	0	100%
45	LCL	0	0.0	1	0	0	0	0	0	0	0	100%
46	20' container	0	0.0	10	0	0	0	0	0	0	0	100%
47	40' container	0	0.0	20	0	0	0	0	0	0	0	100%
48		Either A or B :	0	0	0	0	0	0	0	0	0	
49												
50												
51	Alternative (j) : B	Binary	Container	Delivery qty (plt)	Delivery qty	Delivery cost	Time penalty	Delay cost	Damage cos	Inventory cost	Total cost	Utilization
52	Delivery mode (i)	b_j	z_{ij}	n_i	$b_jz_{ij}n_i$	$b_jz_{ij}cc_{ij}$	$b_jz_{ij}n_i(t_i-t_{min})tc$	$b_jz_{ij}n_idd_{ij}ic$	$b_jz_{ij}n_idm_{ij}p$	$b_jz_{ij}ic_iu_{ij}$		
53	Air	1	0.0	1	0	0	0	0	0	0	0	100%
54	LCL	1	0.0	1	0	0	0	0	0	0	0	100%
55	20' container	1	0.0	10	0	0	0	0	0	0	0	100%
56	40' container	1	13.0	20	260	39,000	277	554	18,170	2,976	60,978	98%
57		Either A or B :	1	260	260	39,000	277	554	18,170	2,976	60,978	
58		A + B =	1	Total delivery =	260							

Figure A 12 Solver of Model 4 (2)