東　　海　　大　　學

工業工程與經營資訊研究所

碩士論文

記憶體模組產業之多階多廠彈性供應網絡生產規劃模式

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中 華 民 國 九 十 九 年 六 月

Multi-level and multi-site flexible supply network planning model for memory module industry

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A Thesis

Submitted to the Institute of Industrial Engineering and Enterprise Information at Tunghai University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Industrial Engineering and Enterprise Information

June 2010

Taichung, Taiwan, Republic of China

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Abstract

Under the global and multi-level, multi-site production environment, production planning is more complex and different than single-site. A memory module industry's supply chain usually consists of multiple manufacturing sites and multiple distribution centers. In order to fulfill the variety of demands from downstream customers, production planners need not only to decide the order allocation among multiple manufacturing sites and shipment among multiple DCs but also to consider memory module industrial characteristics and supply chain constraints, such as multiple material substitution relationships, raw material re-allocation among manufacturing sites, manufacturing sites' direct shipment, capacity constraint, transportation lead time, and production lead time. While the previous researches treat supply network problem as a traditional multi-level supply network model, in which arcs should connect the two adjoining echelons in the network and there are no arcs striding over any abutting echelons, thereby the problem can be solved stage by stage. However, in practice the traditional multi-level supply network model sometime causes problems, such as difficulties in accurate inventory controlling, slow response, and lack of flexibility etc. To solve the flexible multi-level supply network problem, we develop an integer linear programming (ILP) to produce a flexible supply network planning (FSNP) model for memory module industry. The weekly optimal plans are attained by FSNP model for planner's reference which include re-allocation, transportation, and production quantities.

Keywords：flexible supply network planning, order allocation, memory module industry, integer linear programming

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摘要

在全球以及多階多廠區的生產環境之下，生產規劃比單廠區更加複雜與困難，記憶體模組產業之供應網絡通常包含多個製造廠與多個配銷中心，為了滿足下游顧客的多種類需求訂單，規劃人員不只需要決定製造廠的訂單分配或決定由哪一個配銷中心出貨，亦需考量記憶體模組產業的相關特性與供應網絡的限制，例如: 物料替代關係、原物料調撥、製造廠直接出貨給顧客、產能限制、運輸與生產前置時間。但過去的文獻中，甚少針對記憶體模組產業之多廠區生產規劃進行探討，且未同時考量該產業之所有生產特性，因此，本研究使用整數線性規劃模式發展一個以成本極小化為目標的記憶體模組產業之彈性供應網絡生產規劃模式，以期產生每週之生產計劃與運輸計畫，供規劃人員進行生產規劃時之參考依據。

最後，經由實驗得知本模式所適用的產業環境範圍，並進行敏感度分析，最後以企業實際資料作為案例驗證的實證。

關鍵字：彈性供應網絡生產規劃、訂單滿足、記憶體模組產業、整數線性規劃

誌謝

兩年的研究所生涯，終於告一段落了!回首在決定讀研究所時的期待，以及現在收成的喜悅，這一切都要感謝許多人對我的提攜與幫助。

研究所就讀期間，最要感謝的是我的父母親與哥哥，因為他們的支持，我才能心無旁騖地專心於研究上，且要感謝男友俊穎的體諒與打氣，總是耐心地陪我渡過許多內心煎熬的時刻。

本論文得以完成，首先要感謝指導教授 王立志老師以及鄭辰仰老師的教導，在老師辛勞叮嚀論文的進度之下，論文才能夠如期的完成，且讓我有機會瞭解實際業界營運情形，並將理論結合實務，體驗到與別人不同的學習經驗。此外，論文口試期間，承蒙交通大學 鍾淑馨老師及雲林科技大學 袁明鑑老師提供寶貴的意見，使本研究能夠有更完善的成果。

在碩士生活裡，感謝献琨及立品學長，在我做研究感到最迷惘的時候，能適時對我伸出援手並給予明確的建議；此外，還要感謝世倫、怡芳、煥升及禺澐，常常與我一起討論研究與紓解壓力，亦要感謝研究室的學弟妹晉瑋、章昱、閔智、閔雄、惠菁、鈺勛、立楷及忠軒在研究生活上的協助。

王文冠　謹致於

東海大學工業工程與經營資訊學系

民國九十九年六月

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Chapter 1 Introduction

1.1 Background

Enterprises nowadays are facing more challenges because of the evolving globalization and the increasingly severe competitive environment. The manufacturing supply chain environment (MSCE) is one manufacturing problem with a complicated structure. It usually includes several components, such as multiple sites, vendors, products, machines and orders. Some relationships may exist between any pair of those elements, such as multiple levels (stages) and multiple machine structures. For a global company, manufacturing sites may locate in different places geographically; global planners may face order allocation problems to meet demands from different customers at multiple sites (Lin, 2007). Therefore, a complete order allocation model not only needs to consider its strategic and production objectives, but also needs to effectively allocate manufacturing resources to fulfill market and customer demands.

Under the supply network planning, order allocation is a method for allocating order demand (quantity) to the selected manufacturing site in order to optimize the production cost in accordance with an acceptable on-time delivery to guarantee high service levels for customers (Kawtummachai, 2005). Different manufacturing environments, which are classified into three segments, as shown in Figure 1.1, represent the complexity of order allocation problems. The infrastructure of a supply chain environment, depicted in Figure 1.1 (a), shows that customer orders may be fulfilled by distribution centers (DCs) delivery or manufacturing sites' direct shipment. Subsequently, each distribution center may transport finished products to retailers or customers (the second segment). Also, orders arriving (the third segment) may be dynamically assigned to the appropriate distribution centers or manufacturing sites period by period, as shown in Figure 1.1 (b). The flexible supply network planning model can solve problems of high transportation cost, too-long delivery path, other related cost, long response time, and difficulties in accurate inventory controlling, but this makes the solution space to the problem much larger and more complex. (Lin et *al.*, 2007). When an enterprise possesses multiple DCs and manufacturing sites, its manufacturing environment may face multiple site order allocation problems. Re-allocation of materials among distinct manufacturing sites, some of which may be short of materials or capacity, allows effectively fulfilling a customer's demand. To satisfy a customer's product demand, an allocated manufacturing site may employ different types of intermediate products, which may consist of one kind of raw material based on the multiple-to-multiple product structure, as shown in Figure 1.1 (c). In short, a multiple site order allocation plan needs to consider the following decisions: (1) demand fulfillment among distribution centers and manufacturing sites, (2) production planning of intermediate products and raw materials at each manufacturing site, (3) raw material re-allocation among manufacturing sites.

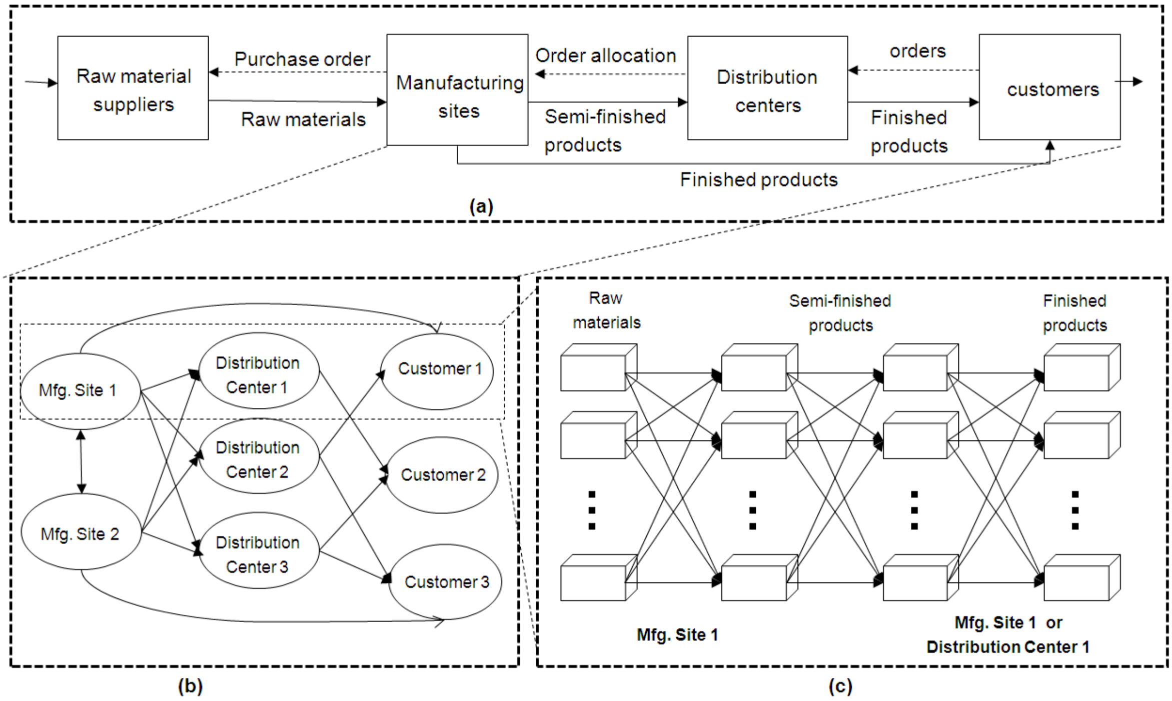


Figure 1.1 (a) Infrastructure of flexible supply chain environment, (b) Supply network between manufacturing sites and customers, (c) Multiple-to-multiple product structure.

In this option of fulfilling an order, products may be shipped directly from the manufacturing plant to the customer, bypassing the distribution center (which takes the order and initiates the delivery request), which is also referred to as directed shipment. Directed shipment has significant advantages over holding inventory, which is the ability to centralize inventories at the manufacturer. A manufacturing site can aggregate demand and provide a high level of product availability with lower levels of inventory than individual distribution centers. The benefits from centralization are highest for high-value, low-demand items with unpredictable demand (Chopra, 2003). All inventories are stored at the manufacturing site, but it may cause a problem when a single customer order includes products from different manufacturing plants and distribution centers. This fragmentation causes an increase in shipping costs and is annoying to customers (Khouja, 2001).

1.2 Motivation

For multi-level and multi-site supply network planning, the current planning method in DRAM industry uses heuristic algorithm, considering transportation lead time and demand quantities of each item but planning according to the sequence by order priority. It will cause the following drawbacks:

1. Demand fulfilment sequence by order priority:
   According to the current planning model, planners fulfill the demand order by order, which may not get the optimum planning result.
2. Plant selection to meet the order:
   Deciding which plant to fulfill demand based on transportation lead time without considering the capacity limit may cause delay or shortage because of insufficient capacity.
3. Sequence of material consumption:
   The approach plans orders by their sequence; therefore, it is only based on the inventory quantities without considering the multiple-to-multiple product structure. It may lead to the situation in which the high priority

order occupies another order having to use the specific raw-material or semi-finished product. Then, the low priority order cannot be satisfied because of material shortage.

4. Shipping option for a distribution network:
   Enterprise only identifies the level of inventory at DCs whether the demand is satisfied or not. Then, it may use directed shipment when the inventory at DCs is insufficient, instead of considering normal shipping and direct shipping simultaneously to get the global optimum solution.

Therefore, the current approach used in DRAM industry may not consume raw-material certainty based on the inventory status and may not consider all kinds of capacity and cost to get the minimum total cost.

Previous research about the supply network planning topic solves those problems by mathematic models, simulations, or heuristic algorithm. However, these methods have some insufficiencies:

1. Mathematic models can get the global optimum but the planning time increases with exponential growth according to the number of variables (e.g. product type, the scale of supply network, demand quantity). If the scale is too large, it may lead to over-long solving time.
2. Simulations and heuristic approach may get local optimum, especially in DRAM Module industry which has multiple-to-multiple substitute product structure. It may not acquire the global optimal allocation of material consumption.
3. The existing research does not explore supply network planning in DRAM Module industry, nor consider the following factors simultaneously:
   (1) Multi-level and multi-site supply network production planning environment
   (2) Customers' demand may fulfil by directed shipment or normal shipment
   (3) Raw material re-allocation among manufacturing sites

(4) Multiple-to-multiple substitute product structure

(5) Capacity limit of manufacturing sites and distribution centers

Therefore, taking supply-driven network into account when considering multi-level and multi-site production environment, we construct a flexible supply network production (FSNP) model under rational planning horizon and resource constraint to find global optimal solutions. They may assist planners to determine resource allocation plan, so it is worth exploring in this research issue.

1.3 Research Objectives

The objectives of this research are:

1. To develop a FSNP model of minimum cost, we consider the characteristics of DRAM Module industry in supply network production environment:
   (1) Multi-level and multi-site supply network production planning environment
   (2) Manufacturing sites' demand fulfilment order by cross-order distribution
   (3) Raw material re-allocation among manufacturing sites
   (4) Multiple-to-multiple substitute product structure
   (5) Capacity limit of manufacturing sites and distribution centers

   Through FSNP model optimal plans of weekly throughput are attained. Re-allocation, transportation, and inventory status are provided to planners as a reference.
2. According to model evaluation and analysis, the following results are explored:
   (1) We expert the FSNP model's computing performance for enterprise.
   (2) The influence of changeable parameters observed by means of sensitivity analysis.

1.4 Outline of the Thesis

The remainder of this study has the following arrangements: Section 2 reviews some related literature regarding supply chain network planning (SNP) problem. In Section 3, describes the problem of this study and a mathematical model of this supply network production planning problem is given. Section 4 present numerical experiments and computational results. Finally, some concluding remarks are presented in Section 5.

Chapter 2 Literature Review

In this chapter, we will review some researches that are related to our research. In section 2.1 we introduce the situation, industry Chains and characteristics in DRAM Module industry. In section 2.2, existing supply network planning researches are reviewed. Then, directed shipment in flexible supply network researches are studied in section 2.3.

2.1 DRAM Module industry status

Currently, the memory module industry's products mainly have applications in the information computer area. A DRAM module, composed of DRAM chips, printed circuit board (PCB), resistors, and capacitors, mounts components on a PCB by employing surface mounting technology (SMT). Gold contact fingers on the PCB connect the memory module with data buses and controller buses of the computer's processer. A DRAM module can access enormous amount of data to a computer's processer, thus increasing an upgraded computer's processing speed and the system's expanded memory. DRAM industry's global market is large-scale, including many well-known companies such as Kingston, Transcend, ADATA, etc.

DRAM Module industry is the midstream of the industry chains, as shown in Figure 2.1.

1. Upstream :

   The upstream suppliers of DRAM Module industry include dynamic random access memory (DRAM), static random access memory (SRAM), FLASH memory, Printed Circuit Board (PCB), CHEPSET, CONNECTER, and electronic component manufacturers.

2. Midstream：

   The midstream industries of DRAM Module industry chain are the manufacturers and trading companies, which employ memory, PCB, CHIPSET and so on, into electronic component products and sell to downstream including application vendors, distribution centers, and customers.

3. Downstream：

The downstream industries of DRAM Module industry chain are electronic product application vendors including mainboard, NB, PC assembled manufacturers, etc.

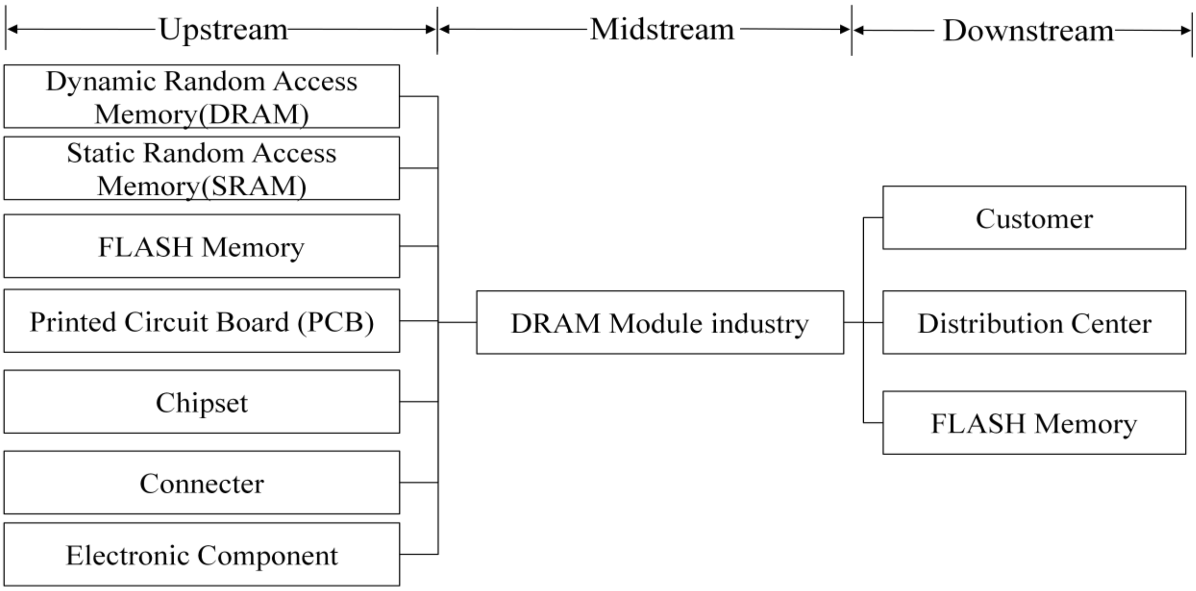


Figure 2.1 DRAM module industry chain

2.2 Supply network production planning literature

Currently, many studies employ different techniques, such as linear programming, simulation, agents, or heuristics searching methods, to solve multi-site order allocation problems. Arntzen (1995) researched a global supply chain model, which is a large mixed-integer linear program that incorporates a global, multi-product bill of materials for supply chains with an arbitrary echelon structure and a comprehensive model of integrated global manufacturing and distribution decisions. Timpe and Kallrath (2000) discussed a planning model which is a mixed-integer linear program that considers multiple demand orders, multi-site transportation, and capacity limits. Guinet (2001) proposed a heuristic planning model for considering various types of products at multiple manufacturing sites to decide multi-site order allocation plans according to a bill of materials (BOM) for each product. Moon *et al*. (2002) employed a genetic algorithm (GA) method to solve multi-site production planning problems by considering capacity constraints and transportation lead times. Nie *et al*. (2006) proposed a genetic algorithm and lagrangian relaxation method to solve multi-site production planning problems. Chern *et al*. (2007) studied a multi-objective master planning algorithm (MOMPA) to solve multi-site master scheduling problems on a multiple product basis. However, the planning ranges of the aforementioned researches only consider single-level and multiple site production environments.

Some other researches consider both multiple levels and multiple site production planning problems. Lendermann and Mcginnis (2001) employed simulation techniques to model a multi-level and multi-site supply chain structure by considering a number of demand products, material substitution relationships, and material re-allocations among manufacturing sites. Chen and Chern (1999) chose a network flow algorithm, such as shortest path algorithm and maximum flow algorithm, to solve problems related to the configuration of supply chain networks. But that research did not consider a manufacturing site's capacity limits. Watson and Polito (2003) discussed a TOC-based heuristics model to solve order allocation problems in a multiple products, multi-level and multi-site environment. Lin and Chen (2007) proposed a mix integer linear programming-based multi-level and multi-site order allocation model by considering demand of different type products, which have material substitution relationships, and capacity limits. But that research did not consider material re-allocations among manufacturing sites. Kanyalkar and Adil (2008) studied a linear programming model to solve order allocation problems in a multiple products, multi-level and multi-site environment. But that research only considers simple BOM structure without the substitution relationships of raw materials. In summary, all of those studies did not consider multiple-to-multiple product structures, which will be discussed in the Section 3.

2.3 Directed shipment in flexible supply network

The normal shipment which arcs should connect the two adjoining echelons in the network and there are no arcs striding over any abutting echelons, thereby the problem can be solved stage by stage as shown in Figure 2.2 (a), therefore, that may cause storage inventory in manufacturing plant and distribution center individual; products may be shipped directly from the manufacturing plant to the customer, bypassing the distribution center (which takes the order and initiates the delivery request), which is also referred to as drop shipping. The manufacturing site has the ability to centralize inventories and make aggregate demand to provide a high level of product availability as shown in Figure 2.2 (b); Using a mix of normal shipment and drop shipment to satisfy demand enables we to capture drop shipment advantages while avoiding its shortcoming as shown in Figure 2.2 (c). It can make the logistics network more flexible and cost-effective than the traditional logistics network.

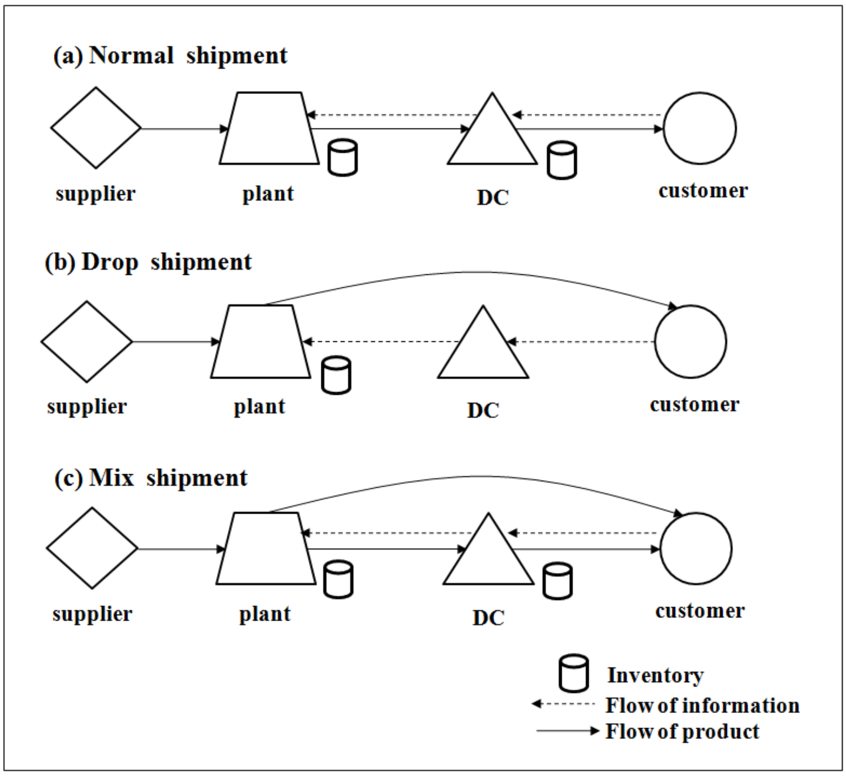


Figure 2.2 Three kinds of different shipment routes

Drop shipping, to transport products from plants to retailers or customers directly, which being close to customers reduces transportation cost and delivery time and increasing customer satisfaction, but a major drawback of drop shipping is that a single customer order may include products from different manufacturers and therefore will be fragmented. Netessine and Rudi (2004) used a game theoretic structure to examine a supply chain with drop-shipping strategy, where a wholesaler decides the optimal order quantity and a retailer decides the customer acquisition cost.

Laporte (1998) described a model in which distribution network structure was defined according to the levels of distribution network and the transportation mode among the different levels. Chopra and Tsai (2002) developed a branch-and-cut approach to solve the multi-level network design problem for minimum cost. Syarif, Yun, and Gen (2002) studied on multi-stage logistics chain network and proposed a spanning tree-based genetic algorithm approach. Zhuan *et al*. (2008) putted forward 0-1 programming model to minimize logistics cost based on 4/R/I/T network structure. The model takes into the restriction of service time limit and sole service characteristics account.

However, in practice this kind of traditional multistage logistics network model sometime causes problems, such as too-long delivery path, slow response etc (Lin *et al*., 2007). Lin *et al*. (2007) proposed an effective hybrid genetic algorithm to solve flexible multistage logistics network (fMLN) design problem with nonadjacent structure, i.e. in this problem some non-neighboring echelons are connected with arcs (nonadjacent connecting arcs). The nonadjacent connecting arcs make the logistics networks cost-effective and adaptable to changes in situation. Lin *et al*. (2009) proposed an effective hybrid evolutionary algorithm (hEA) to solve integrated multistage logistics network model (iMLN) problem, which is considering the direct shipment and direct delivery of logistics and inventory. Its application provides a new potential way to shorten the length between the manufactures and final customers, and to serve the customers flexibly. According to exist studies, flexible supply network planning (FSNP)model, as proved that it can make the logistics network more flexible and cost-effective than the traditional logistics network. But the above-mentioned research only considers directed shipment in flexible supply network without the multiple-to-multiple product substitution relationships.

Chapter 3 Flexible Supply Network Planning Model

3.1 Problem Statement

From an overall perspective, the memory module industry's supply chain network may be divided into three distinct stages. As shown in Figure 3.1, the first stage is suppliers providing raw materials (e.g., DRAM chip and PCB) to manufacturing sites. The second stage represents the production activities of manufacturing sites which employ raw materials to produce semi-finished products (e.g., DRAMs). To shorten order-to-delivery (OTD) time, each manufacturing site may produce semi-finished products based on demand forecasting. In this stage, planners need to decide each site's production schedule and its corresponding purchasing schedule based on available raw materials (e.g., DRAM chip and PCB) and manufacturing capacities. While considering raw material re-allocation plans, planners also need to consider transportation lead times and manufacturing capacity among manufacturing sites to meet due date delivery. At the third stage, distribution centers (DCs) assemble DRAM modules using semi-finished products delivered from appropriate manufacturing site.

When receiving a demand order, DC's planners usually first fulfill the request by using available product inventory. Then, planners may allocate orders to an appropriate manufacturing site providing adequate quantity of semi-finished products to this DC or employing semi-finished product into finished product to fulfill the order if current semi-finished product inventory is insufficient. However, the adoption of fulfillment criteria depends on the due date delivery, inventory status at each manufacturing site, capacity at plants and DCs. The FSNP model may use a mix normal shipment and directed shipment to complete order fulfillment as shown in Figure 3.1. However, directed shipment may make the problem much more difficult and complex, but it may reduce holding cost at DCs substantially and may be adaptable to changes in situations. In addition, the manufacturing site has the ability to centralize inventories and aggregate demands to provide a high level of product availability. As a result, it may avoid bullwhip effect and make the flexible supply network structure more efficient and cost-effective.

According to the memory module industry's manufacturing environment, which is characterized as multi-level and multi-site order allocation, "multi-level" refers to two levels: (1) manufacturing sites for producing raw materials into semi-finished products, and (2) distribution centers for assembling semi-finished products into finished products. The production level has several plants located in different places, resulting in a "multi-site" environment. Besides, it might occur that the raw material is insufficient when producing materials into semi-finished goods in the manufacturing site, so it should re-allocate the raw material from the other manufacturing sites or waiting suppliers to supply material. Hence, it will re-allocate among the manufacturing sites.

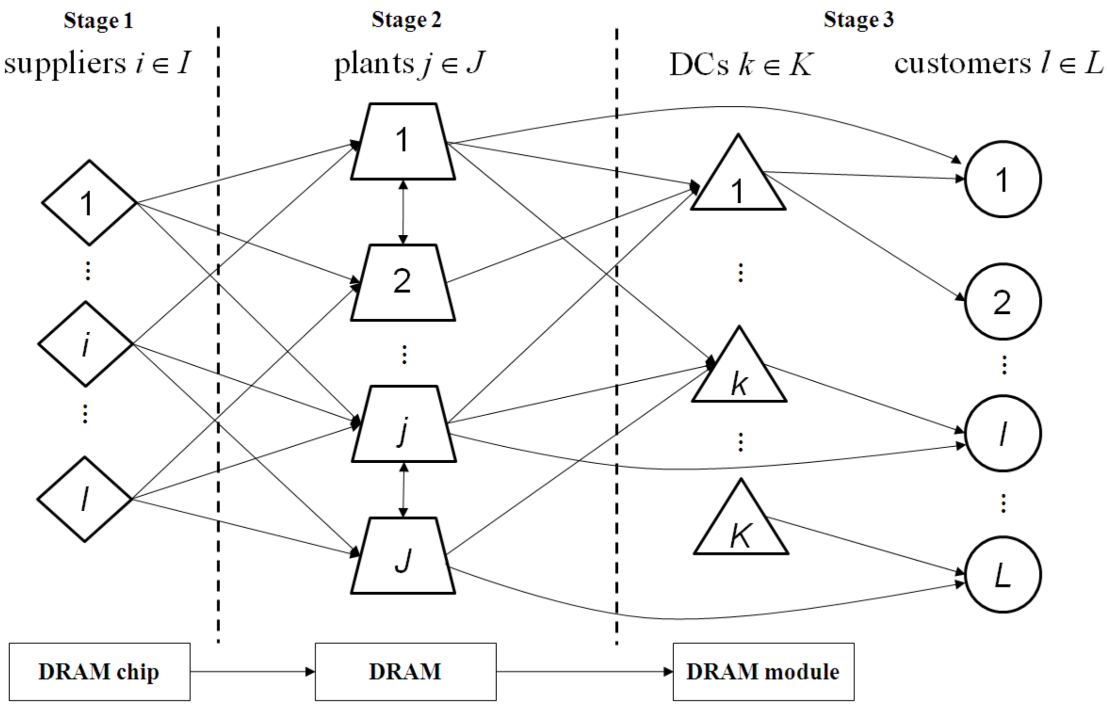


Figure 3.1 Supply chain networks of the memory module industry

In a memory module industry, product structure is very complicated due to the multiple-to-multiple substitution relationship which means a finished product may employ different types of semi-finished products, and the same type of semi-finished product may be assembled into different types of finished products. For example, Figure 3.2 illustrates two different types of finished products: 1G DRAM module and 2G DRAM module. One unit of 1G DRAM module may be assembled by using two units of semi-finished products DRAM 1 (512MB) or one unit DRAM 2 (1G) and one unit of package materials. For the other finished product, one unit of 2G DRAM module may be assembled by using two units DRAM 2 (1G) or one unit DRAM 3 (2G). Therefore, a semi-finished product (e.g., DRAM 2) can be assembled into different finished goods (e.g., 1G or 2G DRAM Module) using different quantities.

Similarly, a semi-finished product may employ different types of raw materials and different types of semi-finished products may be composed of the same type of raw materials. For instance, assembling one unit DRAM 1 (512MB) requires one unit PCB 1 and 32 units DRAM chip 1 (16m) which may be substituted with 16 units DRAM chip 2 (32m). Besides, DRAM chip 2 (32m) can also be assembled into DRAM 3 (2G) by using 64 units.

When having demand request (e.g., DRAM Module 1G), planners not only need to appropriately decide the type and quantity of semi-finished products but also decide the type and quantity of corresponding components/raw materials by considering the multiple-to-multiple product substitution structure. Besides, DRAM chip has high proportion of DRAM module product cost, 80-90 percentages approximately, which affect the DRAM module industry’s profit status. Therefore this research only planning raw material of DRAM chip.

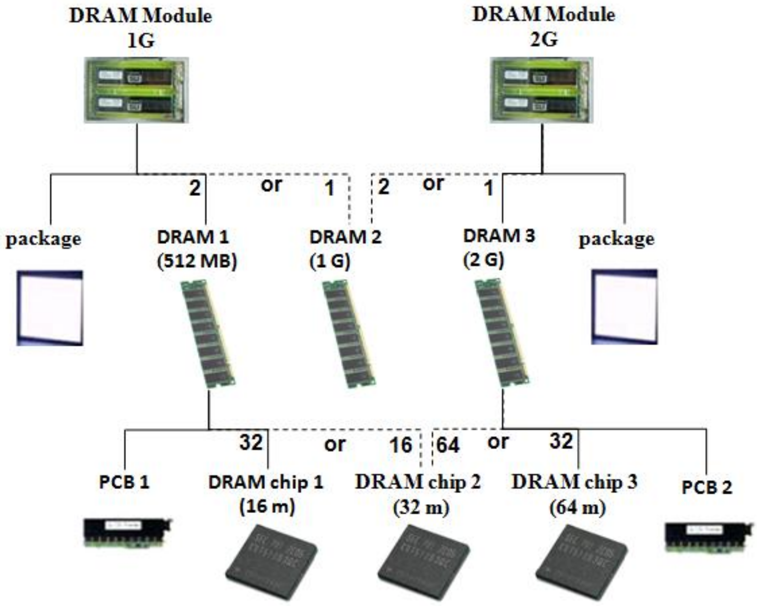


Figure 3.2 A product with multiple to multiple substitution relationship

Since a variety of demands from each distribution center (DC) need to be allocated to different manufacturing sites, planners hope to generate an effective allocation plan based on the aforementioned multiple-to-multiple product structure to avoid the high inventory and the delay of order delivery. Planner's decisions may include: (1) the allocation of semi-finished product types and quantities to an appropriate manufacturing site to fulfill demand orders from a DC which did not have sufficient semi-finished product. Simultaneously, planners have to consider the capacity constraint of manufacturing sites and the multiple-to-multiple product substitution structure. (2) The types and quantities of assembling raw materials to semi-finished products at each manufacturing site based on multiple-to-multiple substitution relationship and the varying DRAM chip prices during different fulfilling periods.

In order to solve the aforementioned supply chain network planning problem for the memory module industry, this study proposes a Flexible Supply Network Planning (FSNP) model which will consider aforementioned important production characteristics: (1) multi-level and multi-site production condition; (2) multiple-to-multiple product substitution structure; (3) manufacturing site can direct shipped products to fulfill customers; (4) raw material re-allocation among manufacturing sites ; (5) capacity limit of each plant; (6) transportation/production lead time; (7) orders' due date ; (8) related cost entries, etc as shown in Figure 3.3.

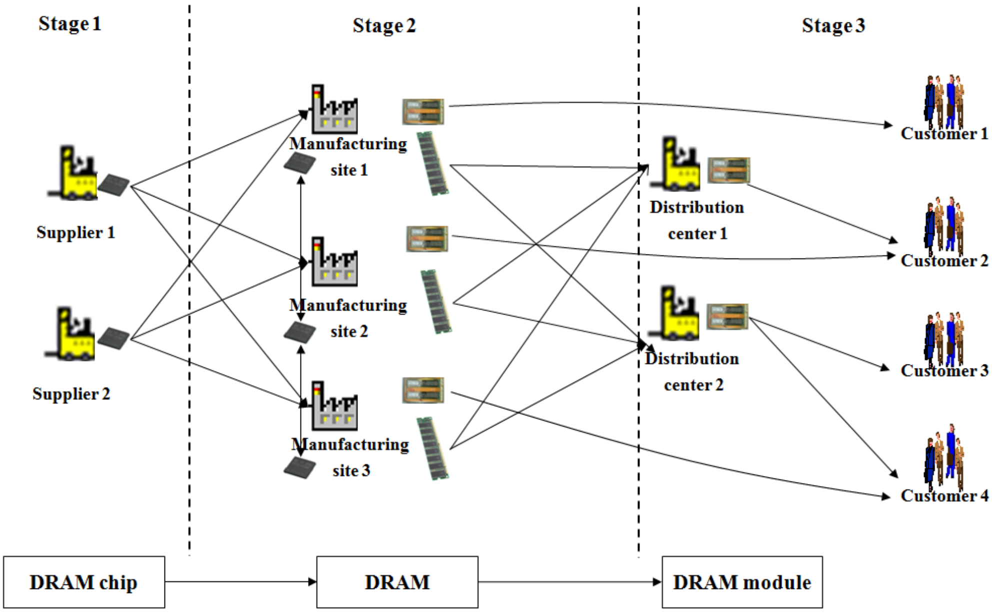


Figure 3.3 The features of memory module industry

3.2 Description of Flexible Supply Network Production Model

3.2.1 Assumption

1. The demand orders all require finished-products.
2. The level of safety stock at each manufacturing sites is not considered.
3. Unit holding cost is constant during planning periods.
4. Production yield and machine breakdown are not considered.
5. Semi-finished products are not allowed to be re-allocated among distribution centers.
6. Scheduled critical components supply plan is known and must be promised.

3.2.2 Obtaining parameters in FSNP model

1. Demand information

   (1) Finished product demand quantities during planning periods.

2. Supply information

   (1) Raw-material supply quantities during planning periods.

   (2) The capacity limit at each manufacturing site for producing semi-finished product and finished product, respectively.

(3) The raw material re-allocation lead time among manufacturing sites.

(4) Given bill of materials (BOMs) for semi-finished product and finished product.

3. Time Information

(1) Transportation lead time from manufacturing sites to distribution centers.

(2) Assembly lead time of semi-finished product to finished product at distribution centers.

(3) Production lead time of raw-material to semi-finished product at manufacturing sites.

(4) Assembly lead time of semi-finished product to finished product at manufacturing sites

4. Cost information

(1) Demand shortage cost

(2) Production cost for finished products

(3) Production cost for semi-finished products

(4) Inventory cost for semi-finished products

(5) Inventory cost for finished products

(6) Inventory cost for raw-materials

(7) Raw material re-allocation cost

3.2.3 Parameters and Variables

Indices

i	index of supplier	($i=1,2,\ldots, I$)
j, j'	index of manufacturing plant	($j,j'=1,2,\ldots, J$)
k	index of distribution center	($k=1,2,\ldots, K$)
l	index of customer	($l=1,2,\ldots, L$)
m	index of material	($m=1,2,\ldots, M$)

s	index of semi-finished good	(*s=1,2,..., S*)
p	index of product	(*p=1,2,..., P*)
t	index of time period	(*t=1,2,..., T*)

Parameters

Time

T_{jk}^{MD} Transportation lead time from manufacturing plant *j* to DC *k*

T_{jl}^{MO} Transportation lead time from manufacturing plant *j* to Customer *l*

T_{kl}^{DO} Transportation lead time from DC *k* to Customer *l*

$T_{j'j}^{F'F}$ Transportation lead time from manufacturing plant *j'* to plant *j*

T_{js}^{FS} Production lead time for semi-finished product *s* at manufacturing plant *j*

T_{jp}^{FP} Assembly lead time for finished product *p* at manufacturing plant *j*

T_{kp}^{DP} Assembly lead time for finished product *p* at DC *k*

Cost

C_l^S Unit delay penalty at order *l*

C_m^{MH} Unit holding cost of material *m*

C_s^{SH} Unit holding cost of semi-finished product *s*

$\mathrm{C}_{\mathrm{jk}}^{\mathrm{MD}}$ Unit transportation cost from manufacturing plant j to DC k

$\mathrm{C}_{\mathrm{kl}}^{\mathrm{DO}}$ Unit transportation cost from DC k to order l

$\mathrm{C}_{\mathrm{jl}}^{\mathrm{MO}}$ Unit transportation cost from manufacturing plant j to order l

$\mathrm{C}_{\mathrm{j'j}}^{\mathrm{F'F}}$ Unit transportation cost from manufacturing plant *j'* to plant *j*

C_{js}^{MS} Unit production cost for producing one unit of semi-finished product *s* at manufacturing plant *j*

C_{jp}^{FSP} Unit production cost for assembling one unit of product *p* at manufacturing plant *j*

C_{kp}^{DSP} Unit production cost for assembling one unit of product *p* at DC *k*

Quantity

D_{lpt} Demand quantity of finished product *p* at distribution center *k* during time period *t*

U_{jt}^{FS} Maximum capacity of semi-finished product *s* at manufacturing plant *j* in period *t*

U_{jt}^{FP} Maximum capacity of product *p* at manufacturing plant *j* in period *t*

U_{kt}^{DP} Maximum capacity of product *p* at DC *k* in period *t*

Q_{ijmt}^{SM} Scheduled supply quantity of material *m* from supplier *i* to manufacturing plant *j* in period t

Product structure

B_{sp}^{SP} Required quantity of semi-finished product *s* to assemble one unit of product *p*

B_{ms}^{MS} Required quantity of raw material *m* to assemble one unit of semi-finished product *s*

Decision Variables

Q_{jmst}^{FMS} Quantity of raw material *m* allocated to produce semi-finished product *s* at manufacturing site *j* in period *t*

Q_{jspt}^{FSP} Quantity of semi-finished product *s* allocated to produce finished product *p* at manufacturing site *j* in period *t*

Q_{kspt}^{DSP} Quantity of semi-finished product *s* allocated to produce finished product *p* at DC *k* in period *t*

Q_{jkst}^{MD} Transportation quantity of semi-finished good *s* from manufacturing plant *j* to DC *k* in period *t*

Q_{klpt}^{DO} Transportation quantity of finished good *p* from DC *k* to Customer *l* in period *t*

Q_{jlpt}^{MO} Transportation quantity of finished good *p* from manufacturing plant *j* to Customer *l* in period *t*

Q_{jmt}^{FMH} Inventory quantity of material *m* at manufacturing plant *j* in period *t*

Q_{jst}^{FSH} Inventory quantity of semi-finished product *s* at manufacturing plant *j* in period *t*

Q_{kst}^{DSH} Inventory quantity of semi-finished product *s* at manufacturing plant *j* in period t

Q_{jpt}^{FPH} Inventory quantity of finished product p at manufacturing plant j in period t

Q_{kst}^{DSH} Inventory quantity of finished product p at DC k in period t

Q_{lpt}^{SH} Shortage quantity of finished product p for order l in period t

Q_{jst}^{FS} Supply quantity of semi-finished product s at manufacturing plant j in period t

Q_{jpt}^{FP} Supply quantity of product p at manufacturing plant j in period t

Q_{jpt}^{DP} Supply quantity of product p at DC k in period t

Q_{jmt}^{RI} Received quantity of material m in manufacturing site j during time period t

$Q_{jj'mt}^{RO}$ Quantity of material m re-allocated from manufacturing site j to manufacturing site j' during time period t

3.2.4 Mathematic Model

The objective of the mathematical model is to obtain the minimum total cost. The objective function is:

Minimize Z =

$$\sum_{l}\sum_{p}\sum_{t}(Q_{lpt}^{SH}\times C_{l}^{S})+\sum_{j}\sum_{m}\sum_{t}(Q_{jmt}^{FMH}\times C_{jm}^{MH})+\sum_{j}\sum_{s}\sum_{t}(Q_{jst}^{FSH}\times C_{js}^{FSH})+$$
$$\sum_{k}\sum_{s}\sum_{t}(Q_{kst}^{DSH}\times C_{ks}^{DSH})+\sum_{j}\sum_{p}\sum_{t}(Q_{jpt}^{MPH}\times C_{jp}^{MPH})+\sum_{k}\sum_{p}\sum_{t}(Q_{kpt}^{DPH}\times C_{kp}^{DPH})+$$
$$\sum_{j}\sum_{k}\sum_{s}\sum_{t}(Q_{jkst}^{MD}\times C_{jk}^{MD})+\sum_{k}\sum_{l}\sum_{p}\sum_{t}(Q_{klpt}^{DO}\times C_{kl}^{DO})+\sum_{j}\sum_{l}\sum_{p}\sum_{t}(Q_{jlpt}^{MO}\times C_{jl}^{MO})+$$
$$\sum_{j'}\sum_{j}\sum_{m}\sum_{t}(Q_{jj'mt}^{RO}\times C_{j'j}^{F'F})+\sum_{j}\sum_{s}\sum_{t}(Q_{jst}^{FS}\times C_{js}^{MS})+\sum_{j}\sum_{p}\sum_{t}(Q_{jpt}^{FP}\times C_{jp}^{FSP})+\sum_{k}\sum_{p}\sum_{t}(Q_{kpt}^{DP}\times C_{kp}^{DSP}) \quad (1)$$

In the mathematical model that follows, the objective function comprises the following components: (1) penalty cost, (2) holding cost of manufacturing plants for material, (3) holding cost of manufacturing plants for semi-product, (4) holding cost of DCs for semi-product, (5) holding cost of manufacturing plants for finish product, (6) holding cost of DCs for finish product, (7) transportation cost from manufacturing plants to DCs, (8) transportation cost from DCs to Customers, (9) transportation cost from manufacturing plants to Customers, (10) re-allocation cost from manufacturing plants to manufacturing plants for material, (11) production cost of manufacturing plants, (12) assembly cost of manufacturing plants, (13) assembly cost of distribution centers.

Solving the supply network production planning of the DRAM module industry, the constraints of this model are as following:

1. Demand and supply balance at each order

$$D_{lpt} = Q_{lpt}^{SH} + \sum_{j}^{J} Q_{jlpt}^{MO} + \sum_{k}^{K} Q_{klpt}^{DO} \qquad \forall l, p, t \tag{2}$$

In practice, customer demand in a specific time period may not always be completely fulfilled in a dynamic market. The sum of supply and shortage quantity should equal the customer demand, as in constraint (2). Demand over a particular period may become a backorder, which will be fulfilled in subsequent periods.

$$Q_{jmt}^{RI} = \sum_{j', \forall j \neq j'}^{J} Q_{j',j,m,t-T_{j'j}^{F'F}}^{RO} \qquad \forall j, m, t \tag{3}$$

The manufacturing site j received re-allocated quantity from other manufacturing sites in period t is equal to the sum of other manufacturing plants (except plant j) re-allocated quantity into manufacturing sites j in period $t - T_{j'j}^{FF'}$ as in constraint (3).

2. Inventory constraints

Customer demand is usually first fulfilled by assembling available semi-finished product inventory at that DC in appropriate time periods. If current available semi-finished product inventory is less than the demand quantity, the unfulfilled quantity may become DC’s semi-finished product requirements which will be allocated from an appropriate manufacturing site by planners.

$$Q_{jmt}^{FMH} = Q_{j,m,t-1}^{FMH} + \sum_{i}^{I} Q_{ijmt}^{SM} + Q_{jmt}^{RI} - \sum_{j'}^{J'} Q_{jj'mt}^{RO} - \sum_{s}^{S} Q_{jmst}^{FMS} \qquad \forall j,m,t \qquad (4)$$

For each manufacturing plant *j*, the inventory at the end of period *t* will be updated by adding the surplus amount which is equal to raw material inventory in period *t*-1 plus scheduled receipts in period *t* and re-allocated quantity from other manufacturing sites in period t and subtracts the re-allocated quantity, which transport to other manufacturing sites in period *t* and actual required quantity of raw material.

$$Q_{jst}^{FSH} = Q_{j,s,t-1}^{FSH} + Q_{jst}^{FS} - \sum_{p}^{P} Q_{jspt}^{FSP} - \sum_{k}^{K} Q_{jks,t+T_{jk}^{MD}}^{MD} \qquad \forall j,s,t \qquad (5)$$

where constraint (5) represents the s^{th} semi-finished product inventory at manufacturing plant *j* in period *t* equals the this semi-finished product's inventory in period *t*-1 plus the produced quantity of semi-finished product in period *t*, and subtracts the quantity of scheduled to assemble into finished product and semi-finished product transported to DC.

$$Q_{kst}^{DSH} = Q_{k,s,t-1}^{DSH} + \sum_{j}^{J} Q_{jkst}^{MD} - \sum_{p}^{P} Q_{kspt}^{DSP} \qquad \forall k,s,t \qquad (6)$$

where constraint (6) represents the s^{th} semi-finished product inventory at DC *k* in period *t* is equal to the semi-finished product's inventory in period *t*-1 plus the produced quantity of semi-finished product in period *t* , and subtracts the quantity of assembling semi-finished product into finished product at DC *k*.

$$Q_{jpt}^{FPH} = Q_{j,p,t-1}^{FPH} + Q_{jpt}^{FP} - \sum_{l}^{L} Q_{jlpt}^{MO} \qquad \forall j,p,t \qquad (7)$$

where constraint (7) represents the p^{th} finished product inventory at manufacturing plant *j* in period *t* is equal to the finished product's inventory in period *t*-1 plus the produced quantity of finished product at manufacturing plant

j in period t , and subtracts the finished product quantity of transporting from manufacturing plant j to customer l.

$$Q_{kpt}^{DPH} = Q_{k,p,t-1}^{DPH} + Q_{kpt}^{DP} - \sum_{l}^{L} Q_{klp,t+T_{kl}^{DO}}^{DO} \qquad \forall k, p, t \qquad (8)$$

where constraint (8) represents the p^{th} finished product inventory at DC k in period t is equal to the finished product's inventory in period t-1 plus the produced quantity of finished product at DC k in period t , and subtracts the finished product quantity of transporting from at DC k to customer l.

3. Product structure constraints

Modeling a multiple-to-multiple product structure requires the separation of assembling (or completing) a final product into two segments: (1) semi-finished products to finished products, and (2) raw materials to semi-finished products, as in constraints (3) and (4), respectively. Since one type of finished product (e.g., 2G DRAM module) may be assembled by choosing more than one type of semi-finished products (e.g., 2G DRAM1 or 1G DRAM2), constraint (3) is employed to identify which types of semi-finished products may be used to assemble certain specific types of finished products. Besides, the finished products may be assembled by different semi-finished products, so the demand quantity of semi-finished good is based on the type.

$$Q_{j,s,t+T_{js}^{FS}}^{FS} = \begin{cases} \sum_{m}^{M} \left(\dfrac{Q_{jmst}^{FMS}}{B_{ms}^{MS}} \right) & \forall j,s,t \quad , \text{ if } B_{ms}^{MS} > 0 \\ \sum_{m}^{M} Q_{jmst}^{FMS} = 0 & \forall j,s,t \quad , \text{ if } B_{ms}^{MS} = 0 \end{cases} \qquad (9)$$

Where Q_{jst}^{FS} denotes the production quantity of semi-finished product s at manufacturing plant j in period t. The demand quantity of semi-finished product s in period t plus production lead time of completing which is obtained by summing of divided raw material's decision variables by the quantity allocated to produce as in constraint (9).

Since one type of semi-finished product (e.g., 2G DRAM) may be assembled by choosing more than one type of raw materials (e.g., 32m DRAM chip or 16m DRAM chip), constraint (10) is employed to identify which type of raw materials may be used to assemble a specific type of semi-finished good.

$$Q^{FP}_{j,p,t+T^{FP}_{jp}} = \begin{cases} \sum_{s}^{S} \left(\frac{Q^{FSP}_{jspt}}{B^{SP}_{sp}}\right) & \forall j,p,t \quad , \text{ if } B^{SP}_{sp} > 0 \\ \sum_{s}^{S} Q^{FSP}_{jspt} = 0 & \forall j,p,t \quad , \text{ if } B^{SP}_{sp} = 0 \end{cases} \qquad (10)$$

Where Q^{FP}_{jpt} denotes the demand quantity of product *p* at manufacturing plant *j* in period *t*. The demand quantity of product *p* in period *t* plus production lead time of completing which is obtained by summing of divided semi-finished product's decision variables by the quantity allocated to produce as in constraint (10).

$$Q^{DP}_{k,p,t+T^{DP}_{kp}} = \begin{cases} \sum_{s}^{S} \left(\frac{Q^{DSP}_{kspt}}{B^{SP}_{sp}}\right) & \forall k,p,t \quad , \text{ if } B^{SP}_{sp} > 0 \\ \sum_{s}^{S} Q^{DSP}_{kspt} = 0 & \forall k,p,t \quad , \text{ if } B^{SP}_{sp} = 0 \end{cases} \qquad (11)$$

Where Q^{DP}_{kpt} denotes the demand quantity of finished product *p* at DC *k* in period *t*. The demand quantity of product *p* in period *t* plus production lead time of completing which is obtained by summing of divided semi-finished product's decision variables by the quantity allocated to produce as in constraint (11).

4. Capacity constraints

$$\sum_{s} Q^{FS}_{jst} \leq U^{FS}_{jt} \qquad \forall j,t \qquad \forall i,m \qquad (12)$$

Constraint (12) ensures that the production load of each semi-finished product *s* assigned to manufacturing plant *j* in period *t* cannot exceed its corresponding maximum capacity.

$$\sum_{p} Q_{jpt}^{FP} \leq U_{jt}^{FP} \qquad \forall j,t \qquad (13)$$

Constraint (13) ensures that the production load of each finished product *p* assigned to manufacturing plant *j* in period *t* cannot exceed its corresponding maximum capacity.

$$\sum_{p} Q_{kpt}^{DP} \leq U_{kt}^{DP} \qquad \forall k,t \qquad (14)$$

Constraint (14) ensures that the production load of each finished product *p* assigned to DC *k* in period *t* cannot exceed its corresponding maximum capacity.

$$Q_{jmst}^{FMS}, Q_{jst}^{FS}, Q_{jspt}^{FSP}, Q_{jst}^{FP}, Q_{kspt}^{DSP}, Q_{kpt}^{DP}, Q_{jkst}^{MD}, Q_{klpt}^{DO}, Q_{jlpt}^{MO} \in N \qquad \forall k,t \qquad (15)$$

Constraint (15) represents the positive integer of the variables.

3.2.5 Illustration of FSNP model

The illustrative case will assume that there are two suppliers, three manufacturing plants, two distribution centers (DCs), and planning horizon is eight periods. For example, DRAM Module A (PA) requires one unit of DRAM A (SA) which may be substituted with two units of DRAM B (SB). Besides, DRAM B can also be assembled by one unit of DRAM chip B or two units of DRAM chip C as shown in Figure 3.4. In terms of products, three finished products PA, PB, and PC may be assembled at each plant or DC which fulfills customer orders. Furthermore, the order fulfilment policy is to make to order (MTO), all production activities will be driven by receiving customer orders.

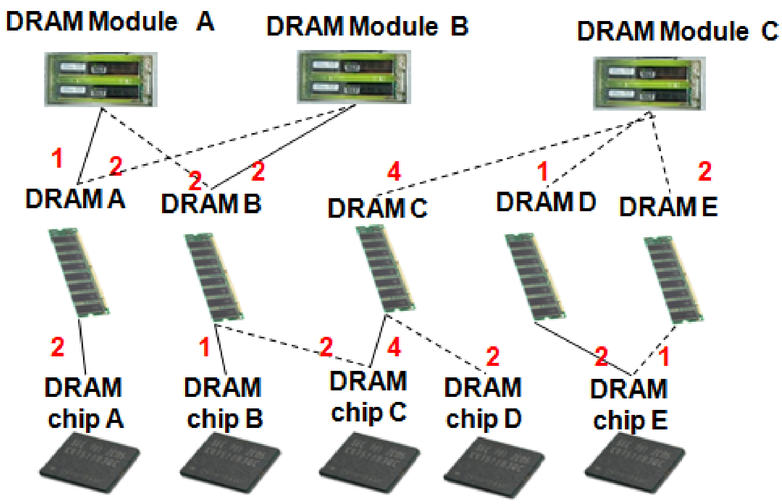


Figure 3.4 The illustration of multiple-to-multiple BOM

An illustration of the main input data for the model includes: (1) Table 3.1 shows the demand for three different products from five customers during the planning periods; (2) Table 3.2 lists the data for transportation costs and lead times from suppliers to plants and from plants to DCs, and (3)

Table 3.3 shows the capacity and production costs for plants and DCs. (4) Table 3.4 shows inventory costs of materials, semi-finished products, and finished products.The scheduled supply of each type material, *m*, at each manufacturing site is 500 units. A planning horizon of 8 weeks is selected in order to be consistent with the company's adopted supply chain operational planning.

Table 3.1 Data for example problem: demand

Customer (l)	Product Type(p)	Quantity(D_{lpt})	Due Day(t)	Penalty Cost(C_l^S)
1	P1	1100	6	$70
2	P1	2500	8	$80
3	P3	1700	8	$90
4	P3	2300	6	$100
5	P3	1800	7	$90

Table 3.2 Data for example problem: transportation cost and lead time

Re-allocated cost ($C_{f'f}^{F'F}$): $10

Transportation lead time between manufacturing sites ($T_{f'f}^{F'F}$): 1 week

Normal Directed		Mfg. (f)			Customer (l)				
		1	2	3	1	2	3	4	5
DC (k)	1	C_{11}^{MD} : $2 T_{11}^{MD} : 1	C_{21}^{MD} : $2 T_{21}^{MD} : 1	C_{31}^{MD} : $2 T_{31}^{MD} : 1	C_{11}^{DO} : $2 T_{11}^{DO} : 1	C_{12}^{DO} : $2 T_{12}^{DO} : 1	C_{13}^{DO} : $2 T_{13}^{DO} : 1	C_{14}^{DO} : $2 T_{14}^{DO} : 1	C_{15}^{DO} : $2 T_{15}^{DO} : 1
	2	C_{12}^{MD} : $2 T_{12}^{MD} : 1	C_{22}^{MD} : $2 T_{22}^{MD} : 1	C_{32}^{MD} : $2 T_{32}^{MD} : 1	C_{21}^{DO} : $2 T_{21}^{DO} : 1	C_{22}^{DO} : $2 T_{22}^{DO} : 1	C_{23}^{DO} : $2 T_{23}^{DO} : 1	C_{24}^{DO} : $2 T_{24}^{DO} : 1	C_{25}^{DO} : $2 T_{25}^{DO} : 1

Drop Shipping		Customer (l)				
		1	2	3	4	5
Mfg. (f)	1	C_{11}^{MO} : $5 T_{11}^{MO} : 1	C_{12}^{MO} : $5 T_{12}^{MO} : 1	C_{13}^{MO} : $5 T_{13}^{MO} : 1	C_{14}^{MO} : $5 T_{14}^{MO} : 1	C_{15}^{MO} : $5 T_{15}^{MO} : 1
	2	C_{21}^{MO} : $5 T_{21}^{MO} : 1	C_{22}^{MO} : $5 T_{22}^{MO} : 1	C_{23}^{MO} : $5 T_{23}^{MO} : 1	C_{24}^{MO} : $5 T_{24}^{MO} : 1	C_{25}^{MO} : $5 T_{25}^{MO} : 1
	3	C_{31}^{MO} : $5 T_{31}^{MO} : 1	C_{32}^{MO} : $5 T_{32}^{MO} : 1	C_{33}^{MO} : $5 T_{33}^{MO} : 1	C_{34}^{MO} : $5 T_{34}^{MO} : 1	C_{35}^{MO} : $5 T_{35}^{MO} : 1

Table 3.3 Data for example problem: capacity

Semi-finished product's manufacturing lead time (T_{js}^{FS}): 1 week
Semi-finished product's manufacturing cost (C_{js}^{MS}): $5
Finished product's manufacturing lead time (T_{jp}^{FP}): 1 week
Finished product's manufacturing cost (C_{jp}^{FP}): $5
Finished product's DC lead time (T_{kp}^{DP}): 1 week
Finished product's DC cost (C_{kp}^{DP}): $5

Mfg. (*f*)	1	2	3
Semi-finished product's capacity (U_{jt}^{FS})	100	900	3000
Finished product's capacity (U_{jt}^{FP})	1000	1500	1500
DC (*k*)	1	2	
Finished product's capacity (U_{kt}^{DP})	2000	2000	

Table 3.4 Data for example problem: inventory cost

Item	Material (m)	Semi-finished product (s)	Finished product (p)
Mfg.(*f*)	C_{jm}^{MH} : \$2	C_{js}^{FSH} : \$5	C_{jp}^{FPH} : \$8
DC (*k*)	-	C_{ks}^{DSH} : \$5	C_{kp}^{DPH} : \$8

For the example illustrated, the solution of FSNP model shown in Table 3.5 may result no shortages orders and total cost of \$214,329.6 after solver iterates 1920 times and run time is 3 seconds. Take demand quantity D_{218} (=2500) as an example, DC 1 provides 1000 units of P1 to customer 2 in period 8, and plant 1 provides 100 units, and plant 2 provides 900 units, and plant 3 provides 500 units of P1 to customer 2 in period 8. We may further show the detailed planning results in Appendix I.

Table 3.5 Results of the FSNP model

Demand site				**Supply site**						
				DC			**Manufacturing Plant**			
Order (*l*)	**Due Date (*t*)**	**Finished Product (*p*)**	**Qty (unit)**	**NO. (*k*)**	**Time Period(*t*)**	**Qty**	**NO. (*j*)**	**Time Period(*t*)**	**Qty**	**Shortage**
1	6	P1	1100	1	6	800	3	6	300	0
2	**8**	**P1**	**2500**	**1**	**8**	**1000**	**1**	**8**	**100**	**0**
							2	**8**	**900**	
							3	**8**	**500**	
3	8	P2	1700	-	-	-	3	8	1700	0
4	6	P3	2300	1	6	100	1	6	100	0
				2	6	1000	2	6	625	
							3	6	475	
5	7	P3	1800	2	7	488	1	7	100	0
							2	7	525	
							3	7	687	

Chapter 4 Model Evaluation and Analysis

In this research, the flexible supply network planning model is solved by *LINGO 10.0 extend*. The model evaluation and analysis is divided into three parts, firstly, because of this study's development of mathematical planning model is integer linear programming, so we will explore the FSNP model' applicable limitation. Secondly, sensitivity analysis, in order to realize the influence on the FSNP model by changing the parameters. Finally, case study, we input the real case of company K to solve the FSNP model and illustrate this optimal planning results. The FSNP model evaluation and analysis is conducted by Window XP Professional SP3 operating system, CPU is Intel Core2 Quad 2.5 GHz, and 1.96 GB RAM.

4.1 The FSNP model's applicable limitation

Integer Linear Programming (ILP) problem is a Non-deterministic Polynomial Hard (NP-hard) problem which cause the solving time increases exponentially when the problem size increases. This propose of this scenario aims at exploring FSNP model's applicable limitation. In this experiment, we use the scale of supply chain and product categories as control factors, and the proxy of performance is time (unit: second). Table 4.1 illustrates the combination of experimental factors which contain 7 product categories and 2 scales of supply chain.

Table 4.1 The combination of experiment factors

Factor	Levels of the factor	Description
The scale of supply chain	Large scale	6 suppliers, 8 manufactures, and 6 DCs
	Small scale	2 suppliers, 3 manufactures, and 2 DCs
Product category	5	5 products, 8 semi-products, 8 materials
	10	10 products, 15 semi-products, 15 materials
	15	15 products, 17 semi-products, 17 materials
	20	20 products, 22 semi-products, 22 materials
	25	25 products, 27 semi-products, 27 materials
	30	30 products, 35 semi-products, 35 materials
	50	50 products, 55 semi-products, 55 materials

In this research, we use five different parameters to plan each combination of experiment factor and repeat experiment a number of times to obtain the average performance. The outcome is summarized in

Table 4.2 and Figure 4.1. The fastest and the slowest solving time for the small size of supply chain are 1.2 seconds and 51.8 seconds, respectively. The fastest and the slowest solving time for the large size of supply chain are 4 seconds and 85.2 seconds, respectively. These results reveal that FSNP model has an acceptable short solving time under each level environment. Moreover, the solving time is exponentially increasing, this phenomenon is more obvious in large scale problem as shown in Figure 4.1.

Table 4.2 Result of the FSNP model's applicable limitation

Supply chain scale \ Product category		5	10	20	25	30	50
Large scale	**Number of variables(units)**	36201	73401	176303	239533	337733	628275
	Run time (seconds)	5.4	14.4	42.6	73.8	85.2	172
Small scale	**Number of variables(units)**	18141	37261	89512	121527	170667	318138
	Run time (seconds)	4.6	6.6	16.6	28.6	51.8	59

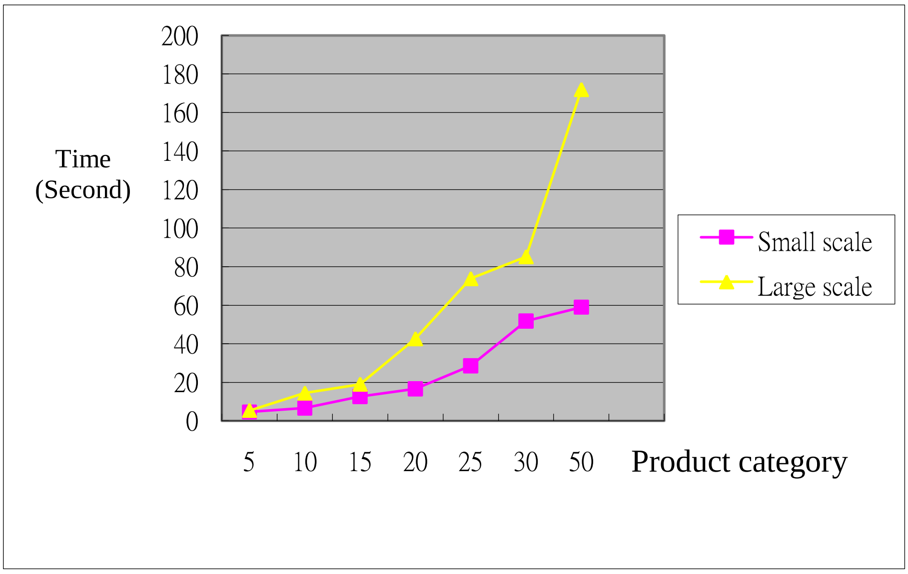


Figure 4.1 Tendency of the FSNP model's applicable limitation

According to the above experimental results known that when the complexity of FSNP model increasing gradually, the solving time is increasing exponentially. Table 4.2 also finds that in the case of the large-scale supply chain scale with fifty product categories, the solving time of FSNP model is excellent.

4.2 Parameter Analysis

Currently, enterprise decides the routes of order fulfilment, which often depends on transportation cost. For instance, direct shipping cost may higher than normal shipping cost, so enterprise adopts distribution centers' product inventory to fulfill demand first. The manufacturing sites may directly ship product to fulfill demand when DC's capacity or semi-finished product is insufficient. However, transportation cost for manufacturing sites is more expensive than normal shipping cost, but the following analysis discovers as unit holding cost is increasing gradually; the overall optimal planning results also adopt direct shipment to customers. For example, the normal shipment transportation cost is cheaper than directed shipment, but the planning result (see Table 4.3) shows that the quantities of directed shipment are more than normal shipment.

Table 4.3 The results with different transportation cost

	T=1	T=2	T=3	T=4	T=5	T=6	T=7	T=8
demand	0	0	0	0	0	34050	31290	16500
transportation cost (plant→DC)	$20	$20	$20	$20	$20	$20	$20	$20
transportation cost (DC → Customer)	$20	$20	$20	$20	$20	$20	$20	$20
plant→DC (units)	**-**	**-**	**-**	**12330**	**6000**	**6600**	**0**	**0**
DC→Customer (units)	**-**	**-**	**-**	**-**	**-**	**12330**	**6000**	**6600**
transportation cost (plant→Customer)	$50	$50	$50	$50	$50	$50	$50	$50
plant→Customer (units)	**-**	**-**	**-**	**-**	**-**	**21720**	**25290**	**9900**

In this research, the experimental analysis explores the transportation lead time from manufacturing sites to customers that observing the changeable ratio of direct shipment under the different levels of inventory cost,. In this case, assuming unit holding cost of the material, semi-finished products, and finished products are the same. The transportation time from manufacturing sites to customers shows in Table 4.4.

Table 4.4 The parameters of two cases

Case	The transportation time from manufacturing sites to customers (period)	Performance
A	2	1.Demand storage quantity 2. The ratio of direct shipment
B	1 (one half)	

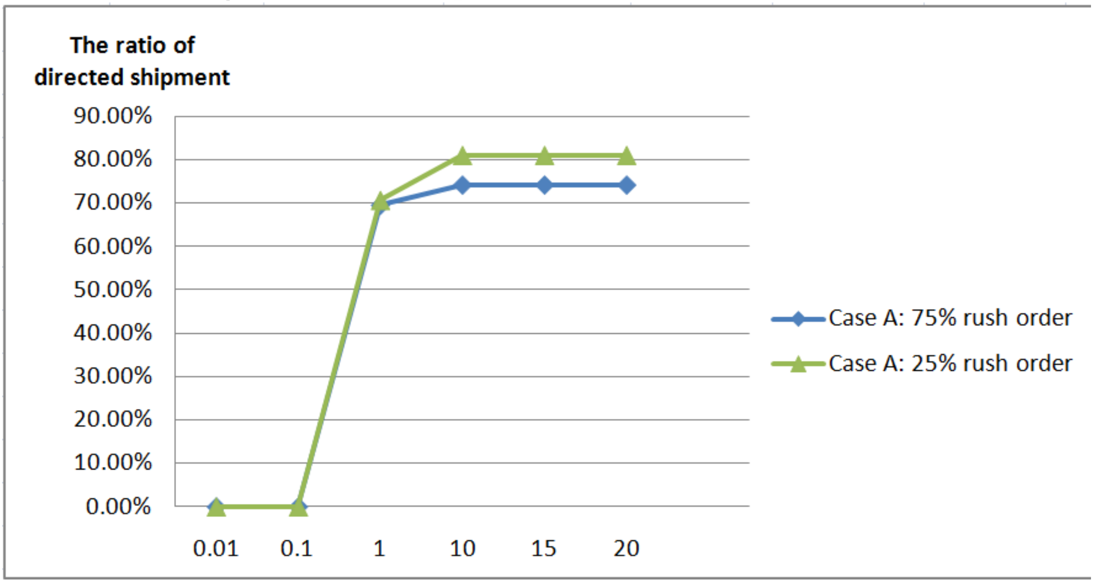
Case A: Direct shipping cost is higher than Normal shipping cost and the transportation time of direct shipment is equal to normal shipment:

The transportation time of direct shipment is equal to normal shipment, but the direct shipping cost is higher than normal shipping cost. Therefore, almost all the transits adopt direct shipment to minimize the total cost. When unit holding cost is increasing gradually, we find the following results in the analysis, when DCs have product inventory on the hand, FSNP model can not consume product inventory at DCs to fulfill customer orders. Owing to consider the multiple-to-multiple substitute product structure, it may consume more inventory of semi-product or material to balance the cost for direct shipment is higher than the cost for normal shipment as shown in Figure 4.2. As a result of the above-mentioned, FSNP model may make the manufacturing sites assemble the semi-finished product into finished product to fulfill customer orders. Besides, we explore two cases: one is 75% rush orders and the other is 25% rush orders. Due to the transportation time of direct shipment can not be reduced, but these two cases do not have significant effect on direct shipment; and the quantities of shortage are shown in Table 4.5.

Table 4.5 The quantity of shortage in case A

Inventory Cost	$0.01	$0.1	$1	$10	$15	$20
75% rush orders	3700	3700	3700	3700	3700	3700
25% rush orders	3000	3000	3000	3000	3000	3000

Figure 4.2 The experimental result of case A



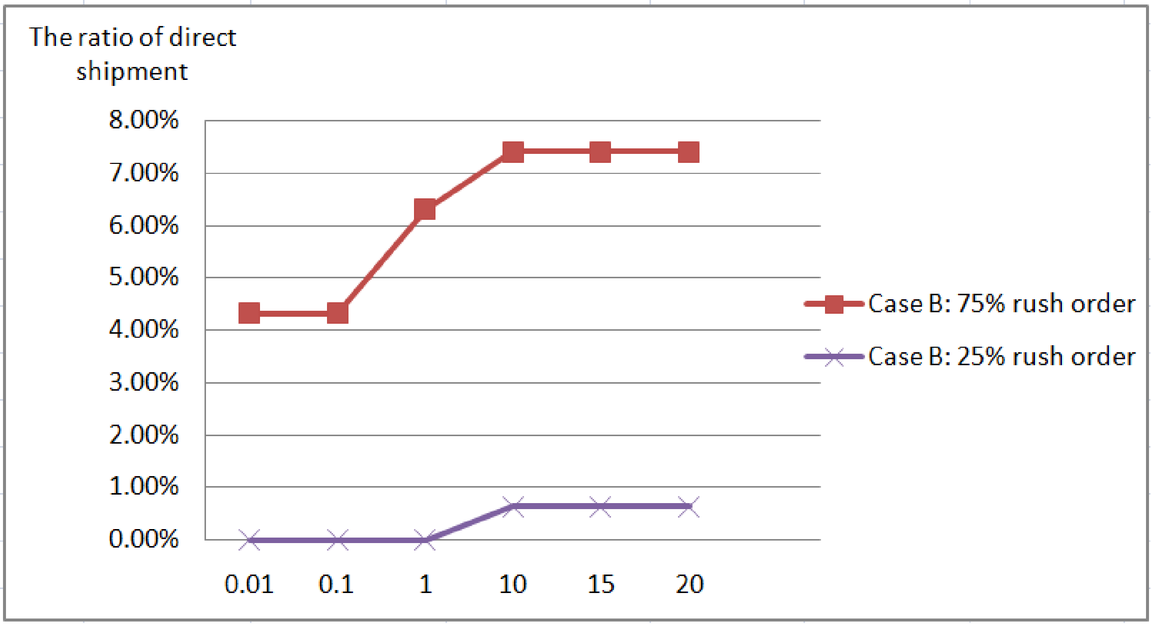
Case B: Direct shipping cost is higher than Normal shipping cost and the transportation time for direct shipment is less than normal shipment:

Although the direct shipping cost is higher than normal shipping cost, the customer orders will be fulfilled by adopting direct shipment to reduce shortage cost, as the ratio of rush order is high. When holding cost per unit is increasing gradually, we get the following results in the analysis, when DCs have product inventory on hand, FSNP model can not consume product inventory in the DCs to meet customer orders. Owing to consider multiple-to-multiple substitute product structure, it may consume more inventory of semi-product or material to balance the cost for direct shipment is higher than the cost for normal shipment as shown in Figure 4.3. As a result of the above-mentioned, FSNP model may make the manufacturing sites assemble the semi-finished product into finished product to fulfill customer orders; and their quantity of shortage as shown in Table 4.6.

Table 4.6 The quantity of shortage in case B

Inventory Cost	$0.01	$0.1	$1	$10	$15	$20
75% rush orders	0	0	0	0	0	0
25% rush orders	0	0	0	0	0	0

Figure 4.3 The experimental result of case B



4.3 Case Study

Evaluation of the proposed ILP-based Flexible supply network problem (FSNP) model uses the case study of company K (a fictitious name chosen in order to preserve the anonymity of the manufacturer). Company K is a leading global memory module company which markets memory module products via three major distribution centers, located in Asia, Europe, and America, and has manufacturing sites throughout Taiwan, China, and America. A data set, generated by scaling down the original problem to a manageable size, is illustrating in the study.

The illustration has the memory module industry's typical planning characteristics: (1) multi-level and multi-site supply chain architecture, which is company K's supply network environment, and (2) multiple-to-multiple product structures, for 100 kinds of different products. There are 1000 units demand orders from 50 customers (as shown in Appendix I). The scheduled supply of each type material, m, at each manufacturing site is 500 units. A planning horizon of 8 weeks is selected in order to be consistent with the company's adopted supply chain operational planning. Based on the mentioned data, the planning result is as shown in Table 4.4. We may further show the detailed planning results in Appendix II.

Table 4.7. Planning Results from the FSNP model

Result	The value objective function	$918,784,100
	Runtime	8'15''
Performance	The ratio of delay order	9.7%
	The ratio of directed shipment	2.14%
	The quantities of re-allocation	4,400,000
	The ratio of order fulfillment	92.3%

Chapter 5 Summary and Conclusion

5.1 Conclusion

This study proposes a flexible supply network planning (FSNP) model to solve a supply network problem for a memory module manufacturing industry. The industrial features include multi-level and multi-site, multiple-to-multiple product substitution structures, resource re-allocation among manufacturing sites, and manufacturing sites' direct shipment. The FSNP model seeks to minimize the total cost. In addition to those particular features, capacity, processing, transportation, production lead times constraints have been included in the model. The proposed FSNP model aims to assist global planners with decisions about production allocation, production types, and quantity of semi-finished (or finished) products per manufacturing site employed, and types/quantities of finished products at each DC assembled. Order allocation plans generated by the FSNP model were superior to that company's current planning method in terms of cost and product shortages. Finally, the analysis shows that the enterprise decides the routes of order fulfilment should not only depend on transportation cost but also the unit holding cost for manufacturing sites and distribution centers.

5.2 Future Research

The FSNP model does not consider the dynamics of raw material prices which causes continuous changes during the planning period. Future research will lengthen the planning period, and take into consideration the estimation of stochastic component cost. Other expansions of this avenue of research will include exploring allocation and transference of raw materials among each manufacturer to avoid purchasing surplus raw materials, and to avoid increasing inventory costs. In addition, transportation activities in a global supply chain, transport tools, capacities, and different countries' traffic. In addition to rapid product delivery issues, narrowing transportation costs to a minimum target level is important.

Reference

[1] Altiparmak, F., and M. Gen (2006), A genetic algorithm approach for multi-objective optimization of supply chain networks, *Computers & Industrial Engineering*, **51**, 197-216.

[2] Arntzen, B. C., and G. G. Brown (1995), Global supply chain management at digital equipment corporation, *Interfaces*, **25**, 69-93.

[3] Chen, S. Y., and C. C. Chern (1999), Shortest path for a supply chain network. *The 4th International Conference, Asia-Pacific Region of Decision Sciences Institute*.

[4] Cheng, C. P., L., C.W., and Liu, C.C. (2000), Unit commitment by lagrangian relaxation and genetic algorithm, *IEEE* **15**(2).

[5] Chern, C.-C. and J.-S. Hsieh (2007), A heuristic algorithm for master planning that satisfies multiple objectives, *Computers & Operations Research*, 3419-3513.

[6] Guinet, A. (2001), Multi-site planning: a transshipment problem, *International Journal of Production Economics*, **74**, 21-32.

[7] Kanyalkar, A. P., and G. K. Adil (2008), A robust optimisation model for aggregate and detailed planning of a multi-site procurement-production-distribution system, *International Journal of Production Research*, **1**-22.

[8] Kawtummachai, R., and N. V. Hop (2005), Order allocation in a multiple-supplier environment, *International Journal of Production Economics*, 231-238.

[9] Nie L.S., Xu X.F., Zhan D.C. (2006), Collaborative planning in supply chains based on Lagrangian relaxation and genetic algorithm, *Computer Integrated Manufacturing Systems*, **11**.

[10] Lendermann, P., B. P. Gan (2001), Distributed simulation with incorporated APS procedures for high-fidelity supply chain optimization, *Winter Simulation Conference*.

[11] Lin, J. T. (2007), A multi-site supply network planning problem considering variable time buckets– a TFT-LCD industry case, *International Journal of Advanced Manufacturing Technology*, **33**.

[12] Moon, C., J. Kim. (2002), Integrated process planning and scheduling with minimizing total tardiness in multi plants supply chain, *Computers & Industrial Engineering.*

[13] Netessine S. and Rudi N. (2004), Supply chain structures on the internet. In: W. Simchi-Levi and M. Shen, Editors. *Handbook of Quantitative Supply Chain Analysis:*

Modeling in the E-Business Era, Kluwer Academic Publishers, Dordrecht (Hingham, MA), 607–641

[14] Timpe, C. H., and J. Kallrath (2000), Optimal planning in large multi-site production networks, *European Journal of Operational Research*, **126**, 422-435.

[15] Watson, K., and T. Polito (2003), Comparison of DRP and TOC financial performance within a multi-product, multi-echelon physical distribution environment, *International Journal of Production Research*, **41**, 741-765.

[16] Wu, D. (2004), Multi-item, multi-facility supply chain planning: models, complexities, and algorithms, *Computational Optimization and Applications*, **28**, 325-356.

[17] Khouja, M. (2001), The evaluation of drop shipping options for e-commerce retailers, *Computers and Industrial Engineering*, **41**, 109-126.

[18] Chopra, S., (2003), Designing the distribution network in a supply chain, *Transportation Research Part E*, **39**, 123-140.

[19] Wang Z., Zhang Q., Yang B., He W. 4/R/I/T distribution logistics network 0-1 programming model and application, *Computers & Industrial Engineering*, **55**, 365-378.

[20] Lin, L., Gen, M. and Wang, X. (2007), A hybrid genetic algorithm for logistics network design with flexible multistage model. *International Journal of Information Systems for Logistics and Management*, **3**(1), 1-12.

APPENDIX I

	Plant (*j*)	DC (*k*)	Semi-finished product (*s*)	Time period (*t*)	Quantity
Q_MD(*j*,*k*,*s*,*t*)	1	1	4	4	100
	2	1	1	4	300
	2	1	1	6	300
	2	2	4	4	500
	3	1	1	4	500
	3	1	1	5	200
	3	1	1	6	500
	3	2	4	4	500
	3	2	4	5	488

	Plant (*j*)	Customer (*l*)	Finished product (*p*)	Time period (*t*)	Quantity
Q_MO(*j*,*l*,*p*,*t*)	1	2	1	8	100
	1	4	3	6	100
	1	5	3	7	100
	2	2	1	8	900
	2	4	3	6	625
	2	5	3	7	525
	3	1	1	6	300
	3	2	1	8	500
	3	3	2	8	1700
	3	4	3	6	475
	3	5	3	7	687

	DC (*k*)	Customer (*l*)	Finished product (*p*)	Time period (*t*)	Quantity
Q_DO(*k*,*l*,*p*,*t*)	1	1	1	6	800
	1	2	1	8	1000
	1	4	3	6	100
	2	4	3	6	1000
	2	5	3	7	488

	Plant (j)	Material (m)	Semi-finished product (s)	Time period (t)	Quantity
Q_FMS(j,m,s,t)	1	1	1	5	200
	1	5	4	2	200
	1	5	4	3	200
	2	1	1	2	600
	2	1	1	4	600
	2	1	1	5	1800
	2	3	3	2	400
	2	3	3	3	1600
	2	3	3	4	400
	2	5	4	2	1000
	2	5	4	3	1000
	2	5	4	4	1000
	3	1	1	2	1000
	3	1	1	3	1000
	3	1	1	4	1000
	3	1	1	5	1000
	3	2	2	3	148
	3	2	2	4	1252
	3	2	2	5	1500
	3	3	2	5	1000
	3	3	3	2	1000
	3	3	3	3	1000
	3	3	3	4	1000
	3	4	3	2	996
	3	4	3	3	1004
	3	4	3	4	996
	3	5	4	2	1000
	3	5	4	3	1176
	3	5	4	4	1000

	Plant (j)	Semi-finished product (s)	Time period (t)	Quantity
Q_FS(j,s,t)	1	1	6	100
	1	4	3	100
	1	4	4	100
	1	4	5	100
	2	1	3	300
	2	1	5	300
	2	1	6	900
	2	3	3	100
	2	3	4	400
	2	3	5	100
	2	4	3	500
	2	4	4	500
	2	4	5	500
	3	1	3	500
	3	1	4	500
	3	1	5	500
	3	1	6	500
	3	2	4	148
	3	2	5	1252
	3	2	6	2000
	3	3	3	748
	3	3	4	752
	3	3	5	748
	3	4	3	500
	3	4	4	588
	3	4	5	500

	Plant (j)	Semi-finished product (s)	Time period (t)	Quantity
Q_FSH(j,s,t)	3	1	4	200

	Plant (*j*)	Semi-finished product (*s*)	Finished product (*p*)	Time period (*t*)	Quantity
Q_FSP(*j*,*s*,*p*,*t*)	1	1	1	6	100
	1	4	3	4	100
	1	4	3	5	100
	2	1	1	6	900
	2	3	3	3	100
	2	3	3	4	400
	2	3	3	5	100
	2	4	3	4	500
	2	4	3	5	500
	3	1	1	4	300
	3	1	1	6	500
	3	2	2	4	148
	3	2	2	5	1252
	3	2	2	6	2000
	3	3	3	3	748
	3	3	3	4	752
	3	3	3	5	748
	3	4	3	4	100
	3	4	3	5	500

	Plant (*j*)	Finished product (*p*)	Time period (*t*)	Quantity
Q_FP(*j*,*p*,*t*)	1	1	7	100
	1	3	5	100
	1	3	6	100
	2	1	7	900
	2	3	4	25
	2	3	5	600
	2	3	6	525
	3	1	5	300
	3	1	7	500
	3	2	5	74
	3	2	6	626
	3	2	7	1000
	3	3	4	187
	3	3	5	288
	3	3	6	687

Q_FPH(j,p,t)	Plant (j)	Finished product (p)	Time period (t)	Quantity
	2	3	4	25
	3	2	5	74
	3	2	6	700
	3	3	4	187

Q_DSP(k,s,p,t)	DC (k)	Semi-finished product (s)	Finished product (p)	Time period (t)	Quantity
	1	4	3	4	1100
	1	4	3	5	488
	2	1	1	4	800
	2	1	1	6	1000

Q_DP(k,p,t)	DC (k)	Finished product (p)	Time period (t)	Quantity
	1	3	5	1100
	1	3	6	488
	2	1	5	800
	2	1	7	1000

Q_RO(j,j,m,t)	Plant (j)	Plant (j)	Material (m)	Time period (t)	Quantity
	1	3	5	2	176

	Plant (*j*)	Material (*m*)	Time period (*t*)	Quantity
Q_FMH(*j*,*m*,*t*)	1	1	2	1000
	1	1	3	2000
	1	1	4	3000
	1	1	5	3800
	1	1	6	4800
	1	1	7	5800
	1	1	8	6800
	1	2	2	1000
	1	2	3	2000
	1	2	4	3000
	1	2	5	4000
	1	2	6	5000
	1	2	7	6000
	1	2	8	7000
	1	3	2	1000
	1	3	3	2000
	1	3	4	3000
	1	3	5	4000
	1	3	6	5000
	1	3	7	6000
	1	3	8	7000
	1	4	2	1000
	1	4	3	2000
	1	4	4	3000
	1	4	5	4000
	1	4	6	5000
	1	4	7	6000
	1	4	8	7000
	1	5	2	624
	1	5	3	1424
	1	5	4	2224
	1	5	5	3224
	1	5	6	4224
	1	5	7	5224
	1	5	8	6224

	Plant (*j*)	Material (*m*)	Time period (*t*)	Quantity
Q_FMH(*j*,*m*,*t*)	2	1	2	400
	2	1	3	1400
	2	1	4	1800
	2	1	5	1000
	2	1	6	2000
	2	1	7	3000
	2	1	8	4000
	2	2	2	1000
	2	2	3	2000
	2	2	4	3000
	2	2	5	4000
	2	2	6	5000
	2	2	7	6000
	2	2	8	7000
	2	3	2	600
	2	3	4	600
	2	3	5	1600
	2	3	6	2600
	2	3	7	3600
	2	3	8	4600
	2	4	2	1000
	2	4	3	2000
	2	4	4	3000
	2	4	5	4000
	2	4	6	5000
	2	4	7	6000
	2	4	8	7000
	2	5	5	1000
	2	5	6	2000
	2	5	7	3000
	2	5	8	4000
	3	1	6	1000
	3	1	7	2000
	3	1	8	3000
	3	2	2	1000

	Plant (j)	Material (m)	Time period (t)	Quantity
Q_FMH(j,m,t)	3	2	3	1852
	3	2	4	1600
	3	2	5	1100
	3	2	6	2100
	3	2	7	3100
	3	2	8	4100
	3	3	6	1000
	3	3	7	2000
	3	3	8	3000
	3	4	2	4
	3	4	4	4
	3	4	5	1004
	3	4	6	2004
	3	4	7	3004
	3	4	8	4004
	3	5	5	1000
	3	5	6	2000
	3	5	7	3000
	3	5	8	4000

	Plant (j)	Material (m)	Time period (t)	Quantity
Q_RI(j,m,t)	3	5	3	176

APPENDIX II

D(*l*,*p*,*t*)				D(*l*,*p*,*t*)			
Customer (*l*)	Finished product (*p*)	Time period (*t*)	Quantity	Customer (*l*)	Finished product(*p*)	Time period (*t*)	Quantity
1	2	7	2000	3	19	7	3000
1	4	8	1100	3	22	8	2500
1	6	7	1900	3	27	8	1600
1	9	8	1200	3	32	7	2000
1	12	7	2800	3	52	7	2700
1	15	8	1400	3	53	7	1900
1	18	7	2700	3	59	8	2000
1	22	8	2600	3	60	8	1000
1	25	8	2300	3	62	7	1000
1	36	7	1200	3	64	8	2000
1	52	7	2000	3	69	7	3000
1	54	8	1100	3	72	8	2500
1	56	7	1900	3	77	8	1600
1	59	8	1200	3	82	7	2000
1	62	7	2800	4	2	8	1900
1	65	8	1400	4	6	8	2000
1	68	7	2700	4	7	7	2700
1	72	8	2600	4	9	7	1000
1	75	8	2300	4	13	8	1000
1	86	7	1200	4	17	5	2000
2	3	6	2700	4	19	7	3000
2	4	7	1900	4	21	7	2500
2	6	8	1000	4	26	6	1600
2	8	7	2000	4	36	7	2000
2	11	7	1000	4	52	8	1900
2	15	7	2000	4	56	8	2000
2	17	8	3000	4	57	7	2700
2	20	8	2500	4	59	7	1000
2	25	8	1600	4	63	8	1000
2	37	6	2000	4	67	5	2000
2	53	6	2700	4	69	7	3000
2	54	7	1900	4	71	7	2500
2	58	7	2000	4	76	6	1600
2	61	7	1000	4	86	7	2000
2	65	7	2000	5	4	7	1900
2	67	8	3000	5	5	7	1000
2	70	8	2500	5	6	8	2700
2	75	8	1600	5	8	7	2000
2	87	6	2000	5	11	7	1000
3	2	7	2700	5	14	8	2000
3	3	7	1900	5	17	7	3000
3	9	8	2000	5	24	8	2500
3	10	8	1000	5	28	8	1600
3	12	7	1000	5	34	5	2000
3	14	8	2000	5	54	7	1900

D(*l*,*p*,*t*)				D(*l*,*p*,*t*)			
Customer (*l*)	Finished product (*p*)	Time period (*t*)	Quantity	Customer (*l*)	Finished product(*p*)	Time period (*t*)	Quantity
5	55	7	1000	7	69	7	3000
5	56	8	2700	7	73	7	2500
5	58	7	2000	7	79	7	1600
5	61	7	1000	7	98	8	2000
5	64	8	2000	8	5	7	1000
5	67	7	3000	8	8	7	2000
5	74	8	2500	8	16	8	2700
5	78	8	1600	8	17	8	1900
5	84	5	2000	8	18	8	1000
6	4	8	1100	8	21	8	3000
6	6	7	1900	8	33	8	1600
6	8	7	2000	8	40	8	2000
6	9	8	1200	8	45	8	2000
6	12	7	2800	8	47	8	2500
6	15	8	1400	8	55	7	1000
6	18	7	2700	8	58	7	2000
6	23	8	2600	8	66	8	2700
6	25	8	2300	8	67	8	1900
6	36	7	1200	8	68	8	1000
6	54	8	1100	8	71	8	3000
6	56	7	1900	8	83	8	1600
6	58	7	2000	8	90	8	2000
6	59	8	1200	8	95	8	2000
6	62	7	2800	8	97	8	2500
6	65	8	1400	9	2	7	2500
6	68	7	2700	9	5	7	1000
6	73	8	2600	9	7	8	2700
6	75	8	2300	9	8	7	2000
6	86	7	1200	9	18	8	2000
7	1	7	2700	9	23	7	2500
7	3	7	1900	9	35	8	1000
7	5	7	1000	9	38	8	3000
7	8	7	2000	9	43	8	1600
7	11	7	1000	9	48	8	2000
7	14	8	2000	9	52	7	2500
7	19	7	3000	9	55	7	1000
7	23	7	2500	9	57	8	2700
7	29	7	1600	9	58	7	2000
7	48	8	2000	9	68	8	2000
7	51	7	2700	9	73	7	2500
7	53	7	1900	9	85	8	1000
7	55	7	1000	9	88	8	3000
7	58	7	2000	9	93	8	1600
7	61	7	1000	9	98	8	2000
7	64	8	2000	10	5	7	1000

D(l,p,t)				D(l,p,t)			
Customer (l)	Finished product (p)	Time period (t)	Quantity	Customer (l)	Finished product(p)	Time period (t)	Quantity
10	7	8	1900	12	19	7	3000
10	8	7	2000	12	25	7	2500
10	12	8	2700	12	28	8	1700
10	14	8	2000	12	45	6	2000
10	19	7	3000	12	51	7	2700
10	27	8	1000	12	54	8	1400
10	34	8	2500	12	57	8	1000
10	42	7	1600	12	58	7	2000
10	50	8	2000	12	61	7	1000
10	55	7	1000	12	67	8	2000
10	57	8	1900	12	69	7	3000
10	58	7	2000	12	75	7	2500
10	62	8	2700	12	78	8	1700
10	64	8	2000	12	95	6	2000
10	69	7	3000	13	7	8	1000
10	77	8	1000	13	11	8	2000
10	84	8	2500	13	15	8	2700
10	92	7	1600	13	17	8	1900
10	100	8	2000	13	18	8	1000
11	4	8	1100	13	21	8	3000
11	6	7	1900	13	35	8	1600
11	10	8	1200	13	42	8	2000
11	12	8	2000	13	45	8	2000
11	15	8	2800	13	48	7	2500
11	16	8	1400	13	57	8	1000
11	18	7	2700	13	61	8	2000
11	24	8	2600	13	65	8	2700
11	25	8	2300	13	67	8	1900
11	36	7	1200	13	68	8	1000
11	54	8	1100	13	71	8	3000
11	56	7	1900	13	85	8	1600
11	60	8	1200	13	92	8	2000
11	62	8	2000	13	95	8	2000
11	65	8	2800	13	98	7	2500
11	66	8	1400	14	3	6	2500
11	68	7	2700	14	5	7	1000
11	74	8	2600	14	10	8	2000
11	75	8	2300	14	17	7	2700
11	86	7	1200	14	18	8	2000
12	1	7	2700	14	25	7	2500
12	4	8	1400	14	34	7	1000
12	7	8	1000	14	39	8	3000
12	8	7	2000	14	44	7	1600
12	11	7	1000	14	49	8	2000
12	17	8	2000	14	53	6	2500

D(l,p,t)				D(l,p,t)			
Customer (l)	Finished product (p)	Time period (t)	Quantity	Customer (l)	Finished product(p)	Time period (t)	Quantity
14	55	7	1000	16	73	8	2700
14	60	8	2000	16	76	8	2300
14	67	7	2700	16	77	8	2600
14	68	8	2000	16	88	8	1200
14	75	7	2500	17	1	7	3000
14	84	7	1000	17	4	8	1900
14	89	8	3000	17	7	8	1000
14	94	7	1600	17	8	7	2000
14	99	8	2000	17	11	7	1000
15	7	8	1900	17	17	8	2000
15	9	8	1000	17	19	8	3000
15	13	7	2700	17	28	8	2500
15	15	8	2000	17	33	8	1600
15	17	8	2000	17	41	8	1600
15	19	7	3000	17	51	7	3000
15	27	8	1000	17	54	8	1900
15	32	8	2500	17	57	8	1000
15	41	8	1600	17	58	7	2000
15	49	8	2000	17	61	7	1000
15	57	8	1900	17	67	8	2000
15	59	8	1000	17	69	8	3000
15	63	7	2700	17	78	8	2500
15	65	8	2000	17	83	8	1600
15	67	8	2000	17	91	8	1600
15	69	7	3000	18	7	8	1000
15	77	8	1000	18	11	8	2000
15	82	8	2500	18	16	4	1900
15	91	8	1600	18	20	8	2700
15	99	8	2000	18	21	8	3000
16	3	8	1800	18	23	8	1000
16	6	7	1900	18	35	8	1600
16	10	8	1200	18	42	8	2000
16	12	8	2000	18	47	8	2000
16	15	8	2800	18	50	7	2300
16	20	7	1400	18	57	8	1000
16	23	8	2700	18	61	8	2000
16	26	8	2300	18	66	4	1900
16	27	8	2600	18	70	8	2700
16	38	8	1200	18	71	8	3000
16	53	8	1800	18	73	8	1000
16	56	7	1900	18	85	8	1600
16	60	8	1200	18	92	8	2000
16	62	8	2000	18	97	8	2000
16	65	8	2800	18	100	7	2300
16	70	7	1400	19	2	8	2500

D(*l*,*p*,*t*)				D(*l*,*p*,*t*)			
Customer (*l*)	Finished product (*p*)	Time period (*t*)	Quantity	Customer (*l*)	Finished product(*p*)	Time period (*t*)	Quantity
19	5	7	1000	21	23	8	2700
19	10	8	2000	21	24	8	2600
19	16	8	2700	21	26	8	2300
19	20	8	2000	21	36	7	1200
19	24	8	2500	21	54	7	1100
19	29	8	1000	21	56	7	1900
19	38	8	3000	21	61	8	1200
19	43	8	1600	21	63	8	2000
19	45	8	2000	21	69	8	2800
19	52	8	2500	21	70	7	1400
19	55	7	1000	21	73	8	2700
19	60	8	2000	21	74	8	2600
19	66	8	2700	21	76	8	2300
19	70	8	2000	21	86	7	1200
19	74	8	2500	22	2	7	3000
19	79	8	1000	22	8	7	2000
19	88	8	3000	22	12	8	1000
19	93	8	1600	22	18	8	2000
19	5	8	2000	22	20	8	1000
20	94	8	1900	22	24	7	1900
20	9	8	1000	22	26	8	2500
20	13	7	2700	22	28	8	3000
20	15	8	2000	22	32	8	1600
20	17	8	2000	22	45	8	2000
20	20	8	3000	22	52	7	3000
20	27	8	1000	22	58	7	2000
20	31	8	2500	22	62	8	1000
20	37	5	1600	22	68	8	2000
20	50	8	2000	22	70	8	1000
20	54	8	1900	22	74	7	1900
20	59	8	1000	22	76	8	2500
20	63	7	2700	22	78	8	3000
20	65	8	2000	22	82	8	1600
20	67	8	2000	22	95	8	2000
20	70	8	3000	23	13	8	1000
20	77	8	1000	23	15	8	2000
20	81	8	2500	23	16	8	1900
20	97	5	1600	23	21	8	3000
20	100	8	2000	23	32	4	1000
21	4	7	1100	23	33	7	1600
21	6	7	1900	23	35	8	2700
21	11	8	1200	23	42	8	2000
21	13	8	2000	23	47	8	2000
21	19	8	2800	23	49	8	2500
21	20	7	1400	23	63	8	1000

D(*l*,*p*,*t*)				D(*l*,*p*,*t*)			
Customer (*l*)	Finished product (*p*)	Time period (*t*)	Quantity	Customer (*l*)	Finished product(*p*)	Time period (*t*)	Quantity
23	65	8	2000	25	77	8	1000
23	66	8	1900	25	81	8	2500
23	71	8	3000	25	87	5	1600
23	32	4	1000	25	100	8	2000
23	83	7	1600	26	2	7	2000
23	85	8	2700	26	4	8	1100
23	92	8	2000	26	6	7	1900
23	97	8	2000	26	9	8	1200
23	99	8	2500	26	12	7	2800
24	4	6	2500	26	15	8	1400
24	7	7	1000	26	18	7	2700
24	14	8	2000	26	22	8	2600
24	16	8	2700	26	25	8	2300
24	23	8	2000	26	36	7	1200
24	31	7	2500	26	52	7	2000
24	37	8	1000	26	54	8	1100
24	39	8	3000	26	56	7	1900
24	46	8	2000	26	59	8	1200
24	50	6	1600	26	62	7	2800
24	54	6	2500	26	65	8	1400
24	57	7	1000	26	68	7	2700
24	64	8	2000	26	72	8	2600
24	66	8	2700	26	75	8	2300
24	73	8	2000	26	86	7	1200
24	81	7	2500	27	3	6	2700
24	87	8	1000	27	4	7	1900
24	89	8	3000	27	6	8	1000
24	96	8	2000	27	8	7	2000
24	100	6	1600	27	11	7	1000
25	6	8	2100	27	15	7	2000
25	10	8	1000	27	17	8	3000
25	14	7	2700	27	20	8	2500
25	16	8	2000	27	25	8	1600
25	17	8	2000	27	40	7	2000
25	23	8	3000	27	53	6	2700
25	27	8	1000	27	54	7	1900
25	31	8	2500	27	56	8	1000
25	37	5	1600	27	58	7	2000
25	50	8	2000	27	61	7	1000
25	56	8	2100	27	65	7	2000
25	60	8	1000	27	17	8	3000
25	64	7	2700	27	70	8	2500
25	66	8	2000	27	75	8	1600
25	67	8	2000	27	90	7	2000
25	73	8	3000	28	2	7	2700

D(l,p,t)				D(l,p,t)			
Customer (l)	Finished product (p)	Time period (t)	Quantity	Customer (l)	Finished product(p)	Time period (t)	Quantity
28	3	7	2300	30	17	7	3000
28	9	8	2000	30	23	7	2500
28	10	8	1000	30	33	8	1600
28	12	7	1000	30	34	5	2000
28	14	8	2000	30	54	7	1900
28	19	7	3000	30	56	8	2700
28	22	8	2500	30	57	8	1000
28	32	7	2000	30	58	7	2000
28	42	8	1600	30	61	7	1000
28	52	7	2700	30	64	8	2000
28	53	7	2300	30	67	7	3000
28	59	8	2000	30	73	7	2500
28	60	8	1000	30	83	8	1600
28	62	7	1000	30	94	5	2000
28	64	8	2000	31	5	8	1100
28	69	7	3000	31	6	7	1900
28	72	8	2500	31	8	7	2000
28	82	7	2000	31	9	8	1200
28	92	8	1600	31	12	7	2800
29	2	8	1900	31	15	8	1400
29	6	8	2000	31	18	7	2700
29	7	7	2700	31	22	8	2600
29	9	7	1000	31	25	8	2300
29	13	8	1000	31	36	7	1200
29	17	5	2000	31	55	8	1100
29	19	7	3000	31	56	7	1900
29	21	7	2500	31	58	7	2000
29	26	6	1600	31	59	8	1200
29	35	7	2000	31	62	7	2800
29	52	8	1900	31	65	8	1400
29	56	8	2000	31	68	7	2700
29	57	7	2700	31	72	8	2600
29	59	7	1000	31	75	8	2300
29	63	8	1000	31	86	7	1200
29	67	5	2000	32	1	7	2700
29	69	7	3000	32	3	7	2500
29	71	7	2500	32	5	7	1000
29	76	6	1600	32	8	7	2000
29	85	7	2000	32	11	7	1000
30	4	7	1900	32	14	8	2000
30	6	8	2700	32	19	7	3000
30	7	8	1000	32	23	7	2500
30	8	7	2000	32	29	7	1600
30	11	7	1000	32	46	8	2000
30	14	8	2000	32	51	7	2700

D(*l*,*p*,*t*)				D(*l*,*p*,*t*)			
Customer (*l*)	Finished product (*p*)	Time period (*t*)	Quantity	Customer (*l*)	Finished product(*p*)	Time period (*t*)	Quantity
32	53	7	2500	34	82	7	1000
32	55	7	1000	34	88	8	3000
32	58	7	2000	34	93	8	1600
32	61	7	1000	34	99	8	2000
32	64	8	2000	35	5	7	1000
32	69	7	3000	35	7	8	1900
32	73	7	2500	35	8	7	2000
32	79	7	1600	35	12	8	2700
32	96	8	2000	35	14	8	2000
33	5	7	1000	35	19	7	3000
33	8	7	2000	35	27	8	1000
33	16	8	2700	35	32	8	2500
33	17	8	1900	35	41	8	1600
33	18	8	1000	35	50	8	2000
33	21	8	3000	35	55	7	1000
33	33	8	1600	35	57	8	1900
33	41	8	2000	35	58	7	2000
33	45	8	2000	35	62	8	2700
33	47	8	2500	35	64	8	2000
33	55	7	1000	35	69	7	3000
33	58	7	2000	35	77	8	1000
33	66	8	2700	35	82	8	2500
33	67	8	1900	35	91	8	1600
33	68	8	1000	35	100	8	2000
33	71	8	3000	36	4	8	1100
33	83	8	1600	36	6	7	1900
33	91	8	2000	36	10	8	1200
33	95	8	2000	36	12	8	2000
33	97	8	2500	36	15	8	2800
34	2	7	2500	36	16	8	1400
34	5	7	1000	36	18	7	2700
34	7	8	2700	36	14	8	2600
34	8	7	2000	36	25	8	2300
34	18	8	2000	36	36	7	1200
34	23	7	2500	36	54	8	1100
34	32	7	1000	36	56	7	1900
34	38	8	3000	36	60	8	1200
34	43	8	1600	36	62	8	2000
34	49	8	2000	36	65	8	2800
34	52	7	2500	36	66	8	1400
34	55	7	1000	36	68	7	2700
34	57	8	2700	36	64	8	2600
34	58	7	2000	36	75	8	2300
34	68	8	2000	36	86	7	1200
34	73	7	2500	37	1	7	2700

D(*l*,*p*,*t*)				D(*l*,*p*,*t*)			
Customer (*l*)	Finished product (*p*)	Time period (*t*)	Quantity	Customer (*l*)	Finished product(*p*)	Time period (*t*)	Quantity
37	3	6	2400	39	34	7	1000
37	7	8	1000	39	39	8	1000
37	8	7	2000	39	44	7	2100
37	11	7	1000	39	47	8	2300
37	17	8	2000	39	53	6	2500
37	19	7	3000	39	55	7	1000
37	25	7	2500	39	60	8	2000
37	29	7	1600	39	67	7	2700
37	45	6	2000	39	68	8	2000
37	51	7	2700	39	74	8	2500
37	53	6	2400	39	84	7	1000
37	57	8	1000	39	89	8	1000
37	58	7	2000	39	94	7	2100
37	61	7	1000	39	97	8	2300
37	67	8	2000	40	7	8	2300
37	69	7	3000	40	9	8	1000
37	75	7	2500	40	13	7	2700
37	79	7	1600	40	15	8	2000
37	95	6	2000	40	17	8	2000
38	7	8	1000	40	19	7	3000
38	11	8	2000	40	27	8	1000
38	15	8	2700	40	32	8	2500
38	17	8	1900	40	41	8	1600
38	18	8	1000	40	49	8	2000
38	21	8	3000	40	57	8	2300
38	35	8	1600	40	59	8	1000
38	43	8	2000	40	63	7	2700
38	46	8	350	40	65	8	2000
38	49	7	1400	40	67	8	2000
38	57	8	1000	40	69	7	3000
38	61	8	2000	40	77	8	1000
38	65	8	2700	40	82	8	2500
38	67	8	1900	40	91	8	1600
38	68	8	1000	40	99	8	2000
38	71	8	3000	41	3	8	1100
38	85	8	1600	41	6	7	1900
38	93	8	2000	41	10	8	1200
38	96	8	350	41	12	8	2000
38	99	7	1400	41	15	8	2800
39	3	6	2500	41	20	7	1400
39	5	7	1000	41	23	8	2700
39	10	8	2000	41	24	8	2600
39	17	7	2700	41	26	8	2300
39	18	8	2000	41	39	8	1200
39	24	8	2500	41	53	8	1100

D(l,p,t)				D(l,p,t)			
Customer (l)	Finished product (p)	Time period (t)	Quantity	Customer (l)	Finished product(p)	Time period (t)	Quantity
41	56	7	1900	43	83	7	1600
41	60	8	1200	43	92	8	2000
41	62	8	2000	43	97	8	1400
41	65	8	2800	43	99	8	2500
41	70	7	1400	44	2	28	2500
41	73	8	2700	44	5	7	1000
41	74	8	2600	44	10	8	2000
41	86	8	2300	44	16	8	2700
41	99	8	1200	44	20	8	2000
42	1	7	3000	44	24	8	2500
42	4	8	1900	44	29	8	1000
42	7	8	1000	44	40	5	3000
42	8	7	2000	44	43	8	1600
42	11	7	1000	44	45	8	2000
42	17	8	2000	44	52	28	2500
42	19	8	3000	44	55	7	1000
42	26	8	2500	44	60	8	2000
42	32	8	1600	44	66	8	2700
42	41	8	2000	44	70	8	2000
42	51	7	3000	44	74	8	2500
42	54	8	1900	44	79	8	1000
42	57	8	1000	44	90	5	3000
42	58	7	2000	44	93	8	1600
42	61	7	1000	44	95	8	2000
42	67	8	2000	45	4	8	1900
42	69	8	3000	45	9	8	1000
42	76	8	2500	45	13	7	2700
42	82	8	1600	45	15	8	2000
42	91	8	2000	45	17	8	2000
43	7	8	1000	45	20	8	3000
43	11	8	2000	45	27	8	1000
43	16	4	1900	45	31	8	2500
43	20	8	2700	45	37	5	1600
43	21	8	3000	45	50	8	2000
43	23	8	1000	45	54	8	1900
43	33	7	1600	45	59	8	1000
43	42	8	2000	45	63	7	2700
43	47	8	1400	45	65	8	2000
43	49	8	2500	45	67	8	2000
43	57	8	1000	45	70	8	3000
43	61	8	2000	45	77	8	1000
43	66	4	1900	45	81	8	2500
43	70	8	2700	45	87	5	1600
43	71	8	3000	45	100	8	2000
43	73	8	1000	46	5	8	1100

D(*l*,*p*,*t*)				D(*l*,*p*,*t*)			
Customer (*l*)	Finished product (*p*)	Time period (*t*)	Quantity	Customer (*l*)	Finished product(*p*)	Time period (*t*)	Quantity
46	6	7	1900	48	35	8	2700
46	11	8	1200	48	42	8	2000
46	13	8	2000	48	47	8	2300
46	19	8	2800	48	50	7	2500
46	20	7	1400	48	63	8	1000
46	23	8	2700	48	65	8	2000
46	24	8	2600	48	66	8	1900
46	26	8	2300	48	71	8	3000
46	36	7	1200	48	82	4	1000
46	55	8	1100	48	83	7	1600
46	56	7	1900	48	85	8	2700
46	61	8	1200	48	92	8	2000
46	63	8	2000	48	97	8	2300
46	69	8	2800	48	100	7	2500
46	70	7	1400	49	3	7	2500
46	73	8	2700	49	7	7	1000
46	74	8	2600	49	14	8	2000
46	76	8	2300	49	16	8	2700
46	86	7	1200	49	23	8	2000
47	2	7	3000	49	31	7	2500
47	8	7	2000	49	37	8	1000
47	12	8	1000	49	39	8	3000
47	18	8	2000	49	48	3	2000
47	20	8	1000	49	49	5	1600
47	24	7	1900	49	53	7	2500
47	26	8	2500	49	57	7	1000
47	28	8	3000	49	64	8	2000
47	32	8	1600	49	66	8	2700
47	46	8	2000	49	73	8	2000
47	52	7	3000	49	81	7	2500
47	58	7	2000	49	87	8	1000
47	62	8	1000	49	89	8	3000
47	68	8	2000	49	98	3	2000
47	70	8	1000	49	99	5	1600
47	74	7	1900	50	5	8	1900
47	76	8	2500	50	10	8	1000
47	78	8	3000	50	14	7	2700
47	82	8	1600	50	16	8	2000
47	96	8	2000	50	17	8	2000
48	13	8	1000	50	23	8	3000
48	15	8	2000	50	27	8	1000
48	16	8	1900	50	31	8	2500
48	21	8	3000	50	37	5	1600
48	32	4	1000	50	50	8	2000
48	33	7	1600	50	55	8	1900

D(*l*,*p*,*t*)				D(*l*,*p*,*t*)			
Customer (*l*)	Finished product (*p*)	Time period (*t*)	Quantity	Customer (*l*)	Finished product(*p*)	Time period (*t*)	Quantity
50	60	8	1000	50	77	8	1000
50	64	7	2700	50	81	8	2500
50	66	8	2000	50	87	5	1600
50	67	8	2000	50	100	8	2000
50	73	8	3000				

Q_MO(*j*,*l*,*p*,*t*)					Q_MO(*j*,*l*,*p*,*t*)				
Plant (*j*)	Customer (*l*)	Finished product (*p*)	Time period (*t*)	Quantity	Plant (*j*)	Customer (*l*)	Finished product(*p*)	Time period (*t*)	Quantity
1	4	17	5	2000	2	30	34	5	2000
1	20	37	5	1600	2	30	84	5	2000
1	25	37	5	1600	2	44	40	5	3000
1	29	17	5	2000	2	49	49	5	1600
1	44	90	5	3000	2	49	99	5	1600
1	45	37	5	1600	3	4	67	5	2000
1	45	87	5	1600	3	5	34	5	2000
1	50	37	5	1600	3	20	87	5	1600
1	50	87	5	1600	3	25	87	5	1600
2	5	84	5	2000	3	29	67	5	2000