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Location Problems for Supply Chain

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1. Introduction

A typical supply chain is a materials and information network composed by supplier, manufactures, logistics agencies, distribution center, warehouse, retailer and consumer. It involves all enterprises and departments throughout the whole product life-cycle from the material gaining, production to semi-finished products or finished products, assembly, transportation, consumption till disposal. Supply chain management is the term used to describe the management of the flow of materials, information, and funds across from those enterprises and departments. It has been proved to be an effective way to enhance enterprises' adaptive ability and viability in the market by collaborating with the upstream and downstream enterprises in the competitive market.

Traditionally, location problem is a branch of operations research concerning itself with mathematical modeling and solution of problems concerning optimal placement of facilities in order to minimize transportation costs, avoid placing hazardous materials near housing, outperform competitors' facilities, etc. Location problems in supply chain management is to find the ideal locations for suppliers, manufactures, distribution centers and warehouses to achieve different objectives by using mathematical modelling, heuristics, and mathematical tools such as, ILOG CPLEX, LogicNetPlus etc.

With the increased environment pollution concerns of people, organizations and governments, enterprises are facing pressure to protect and improve the environment, such as decreasing environment pollution, reducing waste cites and using green raw material etc. In order to solve this problem, enterprises begin to integrate Supply Chain Management (SCM) with the thought of environment protection. With the development of researches on this problem, it naturally comes green supply chain management Stevels (2002). Presently, green supply chain management are mainly focused on the following two aspects: 1) green technology, such as green design, green manufacturing and remanufacturing, waste management, and green logistics and green management Wang et al. (2005). 2) green materials flow, it is to make material flow effective and green by the management of material flow, for example, using green materials, recycling disposal products etc Srivastava (2007). Among those technologies, the approaches for location problems play key roles in green supply chain management.

Motivated by the above problems, we will firstly review the traditional location problem in supply chain management from the following three views: modelling, solving algorithms and mathematical tools, then we will demonstrate the development of location problem in supply chain and propose mathematical model for distribution center location problem in green supply chain. Finally we will illustrate the proposed problem by using IBM Watson Implosion Technology.

2. Literature review

Location theory was first formally introduced in 1909 by Alfred Weber, who considered the problem of deciding a location in the plane to minimize the sum of distance from the distribution center to all demand consumers/retailers. A typical location problem and its solutions are shown in the following two figures. Obviously, the above problem can be
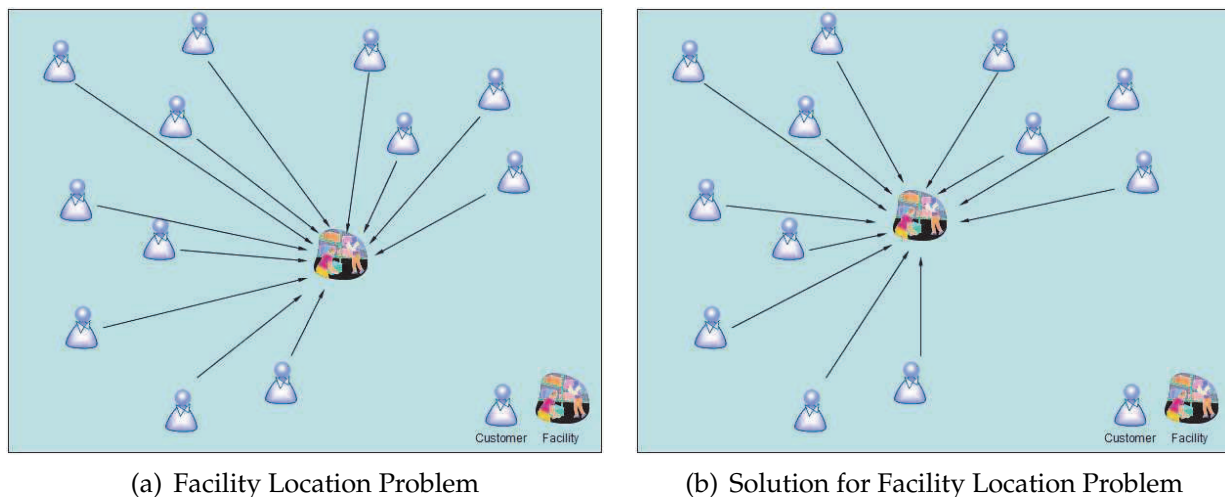

(a) Facility Location Problem   (b) Solution for Facility Location Problem

Fig. 1. Facility Location Problem and Its Solution

described as following mathematical model:

$$\text{Geometric Solution} = \arg\min_{y \in \mathbb{R}^n} \sum_{i=1}^{12} \|x_i - y\|_2 \tag{1}$$

Where $x_1, x_2, \cdots$ and x_{12} are the points where the twelve customers locate, y is position where the facility located.

Based on the simple model provided by Alfred Weber, researchers had proposed lots of models to describe complex location problems for different industries. In fact, location theory is not only a pure mathematical problems, it comes from application, and it also has lots of applications in different industries, such as logistics, public fire protection, manufacture etc. For example, when a supply retailer is thinking to open a new outlets, he will consider customer demands and related costs for different locations. When a manufacturer chooses where to position a warehouse, he will consider customer demand, cost, inventory and cost and market trends of targets locations. When a city planner selects locations for fire stations, he will consider the requirements and constraints for fire fighting. Obviously, those problems are typical location problems.

Although all of those problems are called as location problems, there are many difference in constraints and objectives. Those constraints and objectives are coming from factors/decisions for specific industries Li et al. (2007). For different industries, the factors/decisions are different. For instance, customer demand, population shift and market trends evolve will be considered for a logistics planner when he determine the location for distribution center, minimum transportation time and district coverage rate will be thought for a city planner when he selects locations for fire stations. Because those factors will have impact on the constraints of location model, they will result in lots of challenges for models and algorithms for location problems. According to the objectives of those problems, we can classify those problems as the following six groups,

1) Minimize average travel time/average cost or maximize of net income,

2) Minimize average response time,

3) Minimize maximum travel time/cost,

4) Minimize maximum response time,

5) Maximize minimum or average travel time/cost,

6) Problems with other objectives.

According to the characteristics of those problems, we can identify them as, static and deterministic location problems, dynamic location problems and stochastic location problems. Distribution center location is a typical location problem. Choosing the proper location for a distribution center has developed into a specialized, scientific process. Cost and non-cost factors such as efficient customer access, infrastructure availability, proximity to qualified labor, variable operating costs, incentive availability, and environmental impact are all part of the scientific equation. As a supply chain planner begins the location selection process, the following two questions are very important for him:

1. What are the factors that will control the supply chain decision?

2. What are the steps to properly select a location?

Transportation, the largest location-dependent cost factor, is addressed first. After transportation, labor cost/ productivity, quality, work ethic, and supply, available or develop-able land, power needs, water and waste water supply and capacity, and building costs are considered. Moreover, as basic energy costs have continued to rise, utility costs have become a more important element in the site selection process. Besides those factors, inventory and services costs will also be taken into accounts. When we determine the locations of its distribution centers for a green supply chain, we will consider the other important factor, carbon emissions, besides those factors mentioned above.

2.1 Models for location problem

In order to formulate this problem mathematically, the following notations are necessary:

Inputs:

i = index of customer,

j = index of potential location for distribution center,

k = index of manufacture,

R_i = product requirement for customer i,

P_i = sale price for customer i,

I_j = maximal inventory for potential distribution center location j,
C_j^o = total cost for opening a distribution center at location j,
C_k^p = production cost of manufacture k for single product,
C_{ij} = transportation cost from location j to customer i for unit product,
$\bar{C}_{jk}$ = transportation cost from manufacture k to location j for unit product,
Decision Variables

$$x_j = \begin{cases} 1, \text{ if open a distribution center at location } j, \\ 0, \text{ otherwise.} \end{cases}$$

$$y_{ij} = \text{product transport volume from } j \text{ to } i,$$

$$z_{jk} = \text{product transport volume from } k \text{ to } j,$$

Using these definitions, the model for distribution center location can be described as follows,

$$\max \sum_j \left\{ \sum_i (P_i - C_{ij}) y_{ij} - C_j^o x_j - \sum_k (\bar{C}_{jk} + C_k^p) z_{jk} \right\}$$

$$s.t. \quad \sum_j x_j \cdot y_{ij} = R_i, \qquad\qquad \forall i,$$

$$\sum_i y_{ij} - \sum_k z_{jk} \leq 0, \qquad\qquad \forall j, \qquad (2)$$

$$\sum_k z_{ij} - x_j \cdot I_j \leq 0, \qquad\qquad \forall j,$$

$$x_j \in \{0,1\}, y_{ij} \geq 0, z_{jk} \geq 0, \qquad \forall i,j,k.$$

In model (2), the first constraint is to satisfy each customer demand, constraint from is to meet the requirement that the supply volume of the product at each distribution center should be greater than the demand volume of the product, the third constraint is to limit the total stock volume less than the maximal inventory of each distribution center, the forth constraint is to restrict the decision variable x_j be 0 or 1.

2.2 Algorithms for location problem

In order to solve those problems, the researchers also proposed dozens of exact optimization algorithm and heuristics Brandeau & Chiu (1989); Owen & Daskin (1998); Rosing (1992). The most popular used exact optimization algorithms go as follows, branch-and-bound, branch-and-cut, column generation, and decomposition methods. Where branch-and-bound algorithms sometimes combined with Lagrangian relaxation or heuristic procedures to obtain bounds.

Normally, static and deterministic facility location problems are attractive to be solved by exact optimization algorithms. However, in the real world, the number of decision variables is large and the models are comparatively more complex, it is hard to obtain optimal solution by exact optimization algorithms. There comes the heuristic method. Lagrangian relaxation, linear programming based heuristics and metaheuristics are among the most popular techniques. In fact, most of time the dynamic location problems, stochastic location problems and problems with multiple objectives can only be solved with some specific methodology, heuristics. At the same time, researchers had created and built some useful and innovative tools to help us solve the location problem in supply chain.

2.3 Tools for location problem

The most famous tools for the location problems is IBM ILOG LogicNet Plus XE and Watson Implosion Technology. Below we will illustrate them one by one.

2.3.1 IBM ILOG LogicNet Plus XE

IBM ILOG LogicNet Plus XE is a software for supply chain network optimization and supply chain design, an off-the-shelf decision support solution for ongoing strategic planning. It is for network design and production sourcing. It determines the optimal number, location, territories, and size of warehouses, plants, and lines. It also determines where products should be made and optimizes the carbon footprint. Figure 2 give a typical case for using IBM ILOG LogicNet Plus XE.
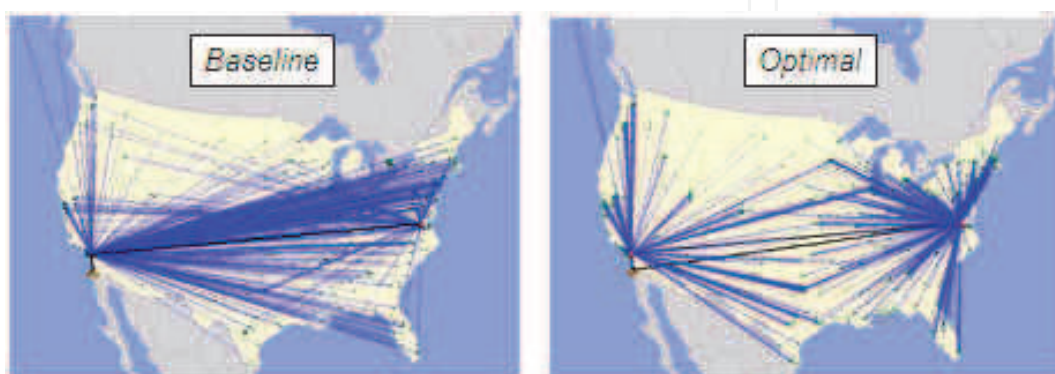
Fig. 2. Typical Case for ILOG LogicNet Plus XE

IBM ILOG LogicNet Plus XE can solve the following typical applications:

1. *Distribution Network Design*, Determine the optimal number, location, and size of distribution facilities to meet customer service requirements at minimum cost.

2. *Manufacturing Network Design*, Determine the best number, location, and capacity of plants, lines, and processes to maximize asset utilization, minimize total cost, and align capacity with business growth projections.

3. *Manufacturing Sourcing Strategy*, In a multiplant environment, determine which product should be made at which plant, trading off manufacturing costs and economies of scale with transportation costs.

4. *Shipping Territory Realignment*, Determine the best service territory for each DC (Distribution Center) to improve service levels and reduce costs.

5. *Network Transition Planning*, Make the transition to a new supply chain configuration focusing on various asset, capacity, inventory and transportation lane requirements.

6. *Seasonal Supply Chain Design*, In a highly seasonal business, determine the appropriate trade-off between capacity and inventory prebuild and the use of overflow facilities.

7. *Contingency Planning*, Understand how unexpected events in the supply chain will affect the costs, service levels, and potential revenues. Develop plans to mitigate the risks.

The major inputs for this tool includes

1. Customer locations and demand by product and time period.

2. Locations, costs, and capacities for plants, suppliers, and production lines for existing and potential sites.

3. Locations, costs, and capacities of existing and potential warehouses.

4. Transportation costs for each lane.

5. Service level requirements.
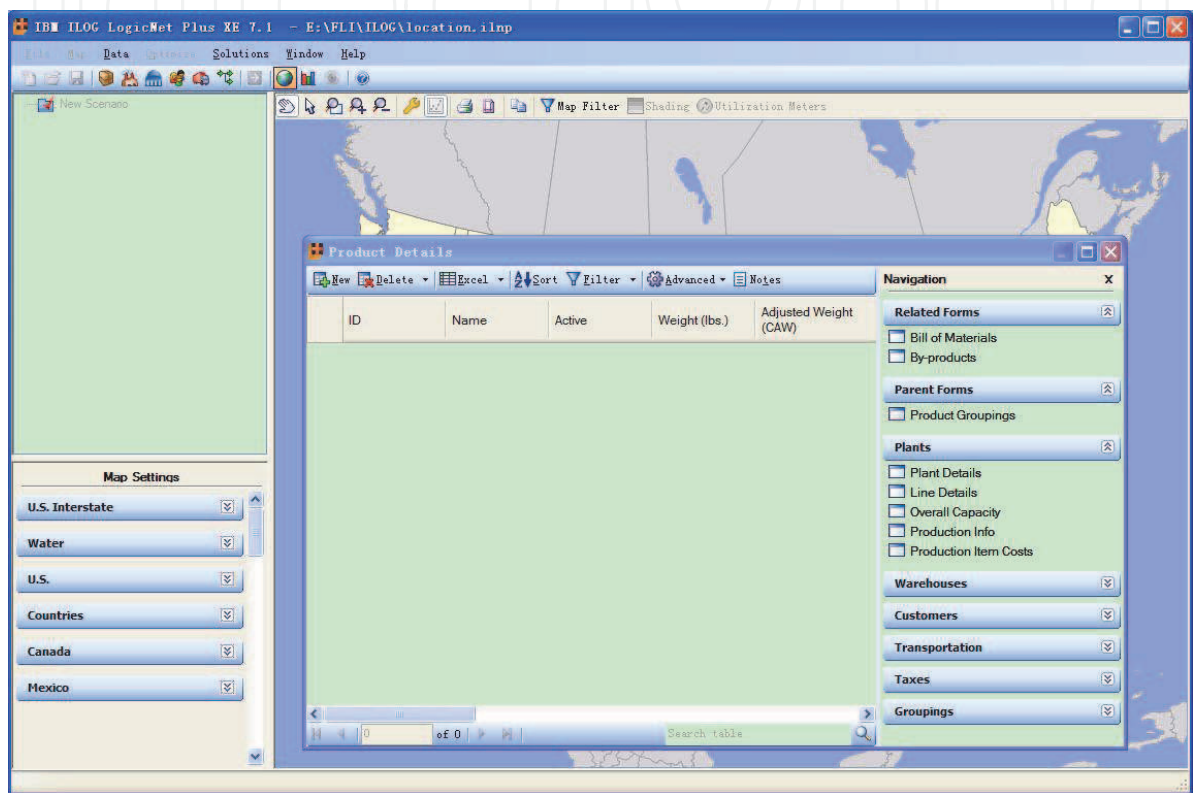
6. Carbon emissions data.

7. Tax rates.

Fig. 3. Screen Shot for ILOG LogicNet Plus XE

Figure 3 is a screen shot for the tool of IBM ILOG LogicNet Plus XE. It will help you to build supply chain for your problem by tables. By using those tables, we can input the data and their relationships for products, by-products, bill of materials, plants, warehouses (distribution centers), customers, transportation, and taxes etc. Once we've finished building the model, we can click on the "Optimize" button to obtain solution for our problems. Integrating with geographic information map, the tool can help us to review the solution through a map. It will visualize the locations for the customer, plants, and distribution center (warehouses). The tool also provide summary report for the solution, including the various input and output parameters for the latest optimization run, such as run time, optimization gap, and the total cost of the solution. This report also has sections on financial summary, cost totals, transportation summary, variable cost details, holding cost details, and manufacturing cost details. Meanwhile we can use the tool to do sensitivity analysis for the model by adjusting the parameters of the model. Although IBM ILOG LogicNet Plus XE has powerful function and can solve several kinds of problems in supply chain management, it cannot support graphical mode to build models.

2.3.2 Watson Implosion Technology

Watson Implosion Technology (WIT) tool is a graphical modeling tool Wittrock (2006), it was generated to solve particular kind of production planning problem, especially for constrained materials management and production planning problem. It utilizes an analytical decision making approach to determine if equipment is worth selling as whole or if it should be dismantled for service parts, which can often yield better returns. It can describe the planning problem as an optimization model by using visual predefined components, and the optimization model will further calculate the number of products to disassemble in a given time period to fulfill the demand for various components. A typical WIT model is should as following Figure 4
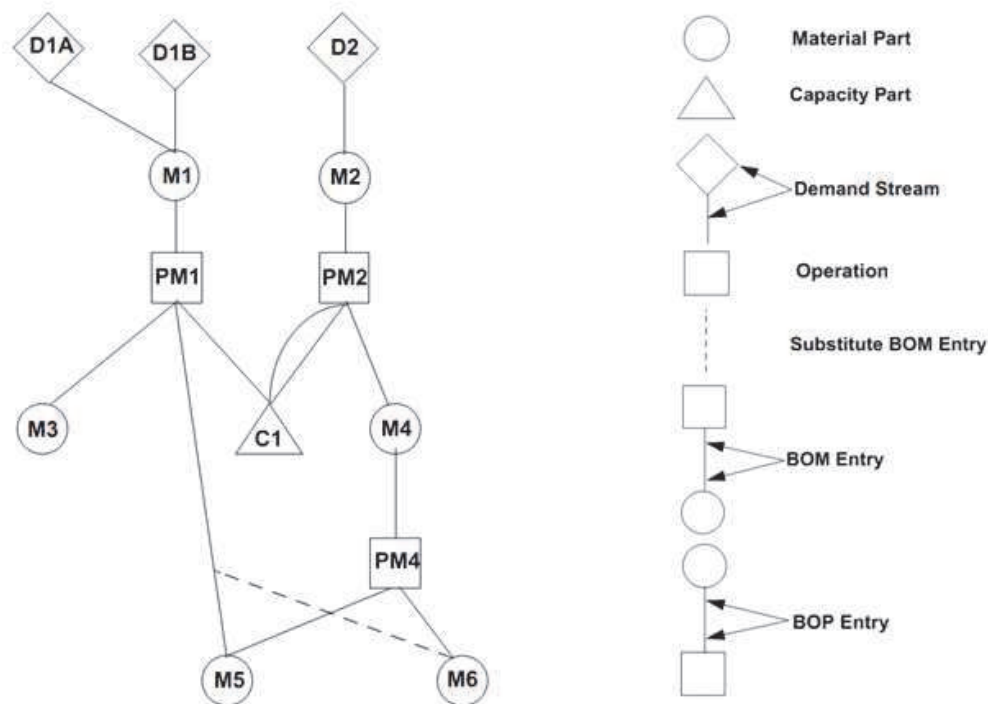
Fig. 4. Typical WIT Model

Table 1 defines all of the manufacturing terms for WIT. The primary data for this software tool is a list of demands for products, a list of supplies for components, and a multi-level bill-of-manufacturing (BOM) describing how to build products from components. Ordinarily, it takes many components to build a single product, and so the list of supplies is much larger than the list of demands. A traditional use of a BOM to perform production planning is Material Requirements Planning (MRP), in which the list of demands for products is "exploded" (via the BOM) into a much larger list of requirements for components. The main capability provided by WIT is, in some sense, the reverse of an MRP explosion: the WIT "implosion". The list of supplies of components is "imploded" via the BOM into a relatively small list of feasible shipments of demanded products. The assumption is that not all demands can be met, and therefore the idea is to make judicious trade-offs between the different demands given limited supplies to best satisfy the manufacturing objectives.

In general, optimizing implosion is used to find the best possible implosion solution according to some well-defined criterion. We can use WIT tool to determine the best possible distribution

Period	The time bucket for production plan.
Part	WIT's concept of a part is very general. A part is either a product or anything that is consumed in order to build a product. This includes both materials and capacities.
Part Category	Parts are classified into two categories: Material and Capacity
Operation	An operation is the means by which parts are dismantled. Specifically, a part is dismantled by "executing" an operation. When an operation is executed, some parts (machines) are consumed, while other parts are produced.
Material	A material part is either a raw material or a product. Any quantity of a material part that is not used in one period remains available in the next period. In other words, material parts have stock.
Capacity	A capacity represents some limitation on the quantity of one or more operations that can be executed during one period. We assume no capacity limitation at dismantling or refurbish centers.
BOM (Bill-of-Manufacturing /Materials)	Each operation has a bill-of-manufacturing that specifies the how parts (both material and capacity) are consumed when the operation is executed. In MRP terms, this is roughly equivalent to a combined bill-of-material and bill-of-capacity.
BOM entry	A BOM entry is the association between a particular operation and one particular part in its BOM. Each BOM entry represents the consumption of some volume of a part in order to execute some operation.
BOP (Bill-of-Products)	Each operation has a bill-of-products that specifies the how parts are produced when the operation is executed. Production rates indicating how much of the part is produced, and so on.
BOP entry	A BOP entry is the association between a particular operation and one particular part in its BOP. Each BOP entry represents the production of some volume of a part as a result of executing some operation.
Product	Any part that appears as the produced part of a BOP entry.
Demand	Each material part may optionally have one or more demands associated with it. A demand stream represents an external customer who places demands for the part.

Table 1. Definition of WIT Terms

center locations and transportation modes for delivering the products given a defined set of criteria. In the following section we will use this tool to illustrate the proposed models.

3. Distribution center location in green supply chain

The concept of green supply chain was first introduced in 1996. Since green supply chain was given it has been getting a lot of attention. It aims to not only synthetically consider the environment impacts and resources utilization in the manufacturing supply chain but improve good business sense and obtain higher profits Wilkerson (2005). Green supply chain

management involves a fundamental rethinking of supply chain management practices and how they can be integrated with your company's environmental strategy, such as, carbon emission and power consumption etc.

Distribution center is a core part for a supply chain. A typical structure is shown in Fig.5, while warehouses are distribution centers which connect factories and retailers. A suitable distribution center location can help us reduce the transportation cost, operation cost of the supply chain and improve the operation efficiency and logistics performances . It is a crucial question in the design of efficient logistics systems to identify the distribution center location Blanchard (2010). Currently choosing the proper location for a distribution center has been developed into a specialized, business and scientific process. It will consider cost and non-cost factors such as efficient customer assess, infrastructure availability, proximity to qualified labor, and variable operating costs. With the increasing concerns on global warming of environmental challenge, the decision to curtail carbon emission become more and more serious for all of the poor and rich countries Akerlof (2006). That makes reducing carbon dioxide emission become a key problem for green supply chain, especially for the distribution center location problems.
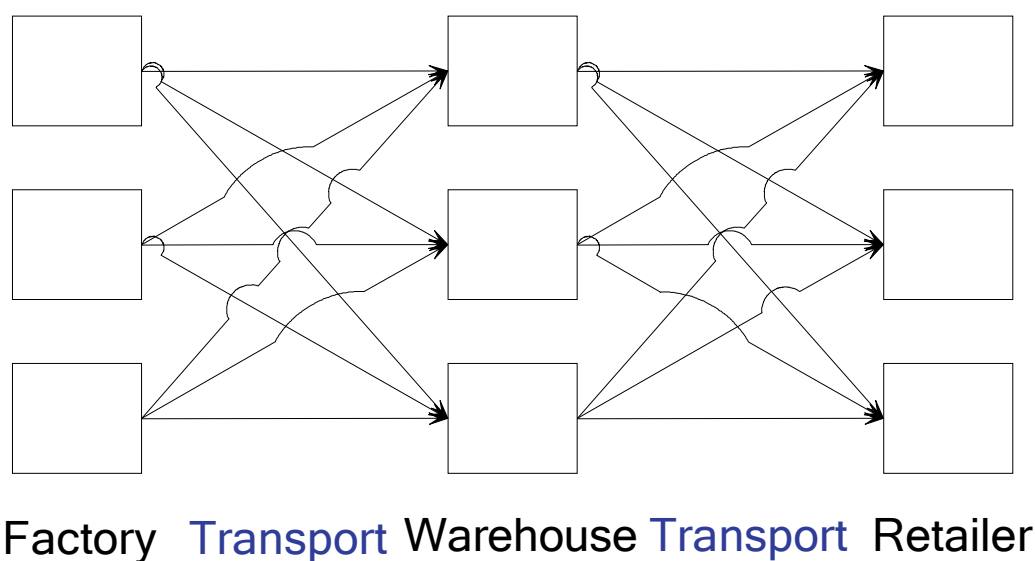

Fig. 5. Typical Distribution Center Location Problem.

3.1 Problem statement

As shown in Fig.5, distribution center location for green supply chain is to determine several locations for distribution centers in a supply chain while pursuing minimal operations cost, carbon emission, maximal profits, considering inventory constraints and satisfying customer demands.

3.2 Mathematical model

Model (2) is a typical description for distribution center location problem. It is to maximize its profits and minimize operations costs while considering inventory and customer demand constraints. However it has ignored an important factor for green supply chain. That's the carbon emission. Carbon emission is related with the manufacture and transportation. Carbon

dioxide will be generated during the production and transportation process, and energy will be consumed during those process. Below we do not consider how to improve the production technology of each manufacture in order to reduce the carbon emission. We suppose the carbon emission for producing a product are fixed for every manufacture, and they can be different for different manufactures. Using the above notations, we can get the following multiple objective mathematical model,

$$\max \sum_j \left\{ \sum_i \left(P_i \cdot y_{ij} - \sum_m C_{ij}^m \cdot u_{ij}^m \right) - C_j^o \cdot x_j - \sum_k \left(C_k^p \cdot z_{jk} + \sum_m \bar{C}_{jk}^m \cdot v_{jk}^m \right) \right\}$$

$$\min \sum_m \sum_j \left\{ \sum_k v_{jk}^m \cdot (\bar{E}_{jk}^m + V_m \cdot E_k) + \sum_i u_{ij}^m \cdot E_{ij}^m \right\}$$

$$s.t. \quad \sum_j x_j \cdot y_{ij} = R_i, \qquad\qquad \forall i,$$

$$\sum_m V_m \cdot u_{ij}^m = y_{ij}, \qquad\qquad \forall i, \forall j, \qquad\qquad (3)$$

$$\sum_m V_m \cdot v_{jk}^m = z_{jk}, \qquad\qquad \forall j, \forall k,$$

$$\sum_i y_{ij} - \sum_k z_{jk} \le 0, \qquad\qquad \forall j,$$

$$\sum_k z_{ij} - x_j \cdot I_j \le 0, \qquad\qquad \forall j,$$

$$x_j \in \{0,1\}, y_{ij} \ge 0, z_{jk} \ge 0, \qquad \forall i, j, k.$$

where, m represent the number of types for transportation mode used to transfer product from manufactures to distribution centers and from distribution centers to customers. u_{ij}^m and v_{jk}^m denote the transportation round times of mode m from the j-th distribution center to the i-th customer and from the k-th manufacture to the j-th distribution center, respectively. C_{ij}^m and $\bar{C}_{jk}^m$ denote the cost of mode m for single transportation round from from the j-th distribution center to the i-th customer and from the k-th manufacture to the j-th distribution center, respectively. E_k denote carbon emission for producing single product at the k-th manufacture, respectively. E_{ij}^m denote carbon emission of mode m for a round transportation from the j-th distribution center to the i-th customer, $\bar{E}_{jk}^m$ denote carbon emission of mode m for a round transportation from the k-th manufacture to the j-th distribution center, V_m denote volume of mode m for single round transportation.

Model (3) is a bi-objective mathematical programming, the first objective is to maximize the profits of the supply chain, the second objective is to minimize the carbon emission of the supply chain. At the first glance there is no relationship between these two objectives. In fact, these two objective are dependent. For example, if we decrease the transportation cost, let's say, decrease the gas consumption, we will cut down the carbon emission of the transportation. In this paper, we will assume the the carbon emission for transportation is a function of the transportation cost and the carbon emission for different manufacture is also a function of the manufacture cost for that factory.

3.3 Algorithms and experiments

Using WIT tool, It is easily for us to translate the model (2) from mathematical equations into a visual WIT model. The WIT model is shown as Fig.6, where,
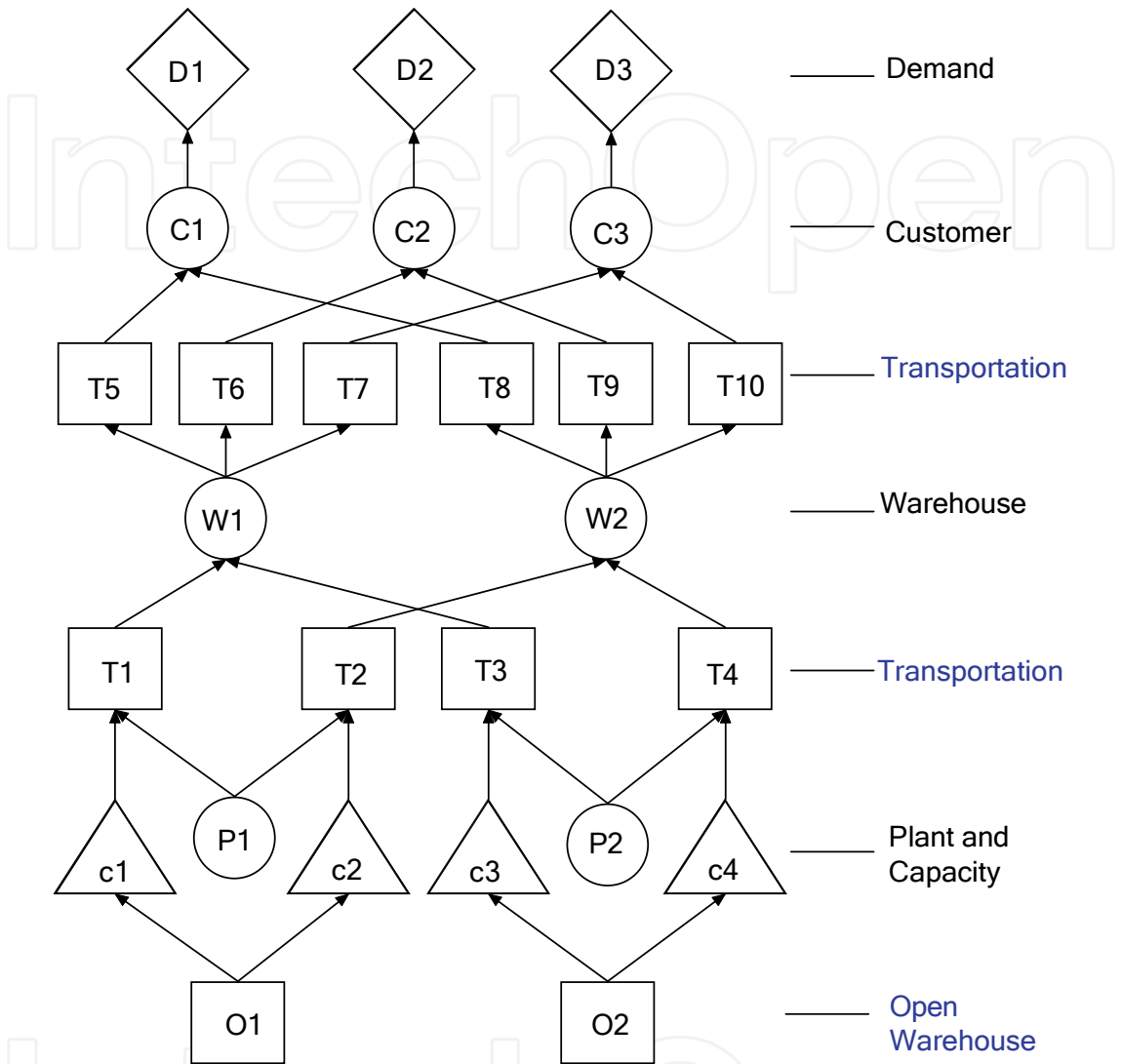

Fig. 6. WIT Model for Model 2

- P1-2: products in factory, defined as materials;
- W1-2: products in warehouse, defined as materials;
- C1-3: products for customer, defined as materials;
- D1-3: demands from customer;
- T1-10: transportation defined as operation, which move products from factory to warehouse, or from warehouse to retailer/customer;
- O1-2: open warehouse/(distribution center) defined as operation. Once a open warehouse operation is executed, the warehouse can be used;
- c1-4: capacity, which is generated only when the warehouse is opened. Specially, it is consumed by each transportation operation.

In the WIT model for model 2, we suppose that all potential distribution center locations can be used for storing products and while we open a distribution center it will have a capacity for transportation. It will be consumed for each transportation. If the warehouse is not opened, the capacity is zero which prevent the products to be transported to this warehouse. There is a solid fee to open a warehouse, which is modeled as the execution cost of the open warehouse operation. Perfect locations of warehouse are near to both factory and customer, and they are influenced by the production supplying from factory, demands from customer and transportation fees. Our WIT model can optimize the warehouse location given all these information. If we suppose that production supplying and demands are fixed, how will the transportation fee influence the location of distribution center? We will demonstrate the influence in the following experiments.

Just as we mentioned above, distribution center locations are influenced by transportation fees if product supplying from factory and demands from customer are fixed. Transportation fee is closely related with the crude oil price, and we can conclude the transportation fees' change from the crude oil price change. In order to illustrate the impact of the variation of the crude oil price on the distribution center location and transportation mode option for green supply chain, we increase the price of the oil from 75$ to 200$ and here is the numerical examples and their result we have. For this case, we have 3 factories located at different places, where the production cost are different because of the raw materials supply and labor supply, we have 15 potential locations where we can open a distribution center/warehouse, 200 customers/retails at different locations. While we increase the crude oil price we found we will open more distribution center in order to decrease our operation cost, especially for the transportation cost. In Fig. 7 we have shown the relationship between the number of opened distribution centers and the crude oil prices. In Fig. 8 we have shown the relationship between profits and crude oil prices. From those two above figures we can easily found that as the increase of the
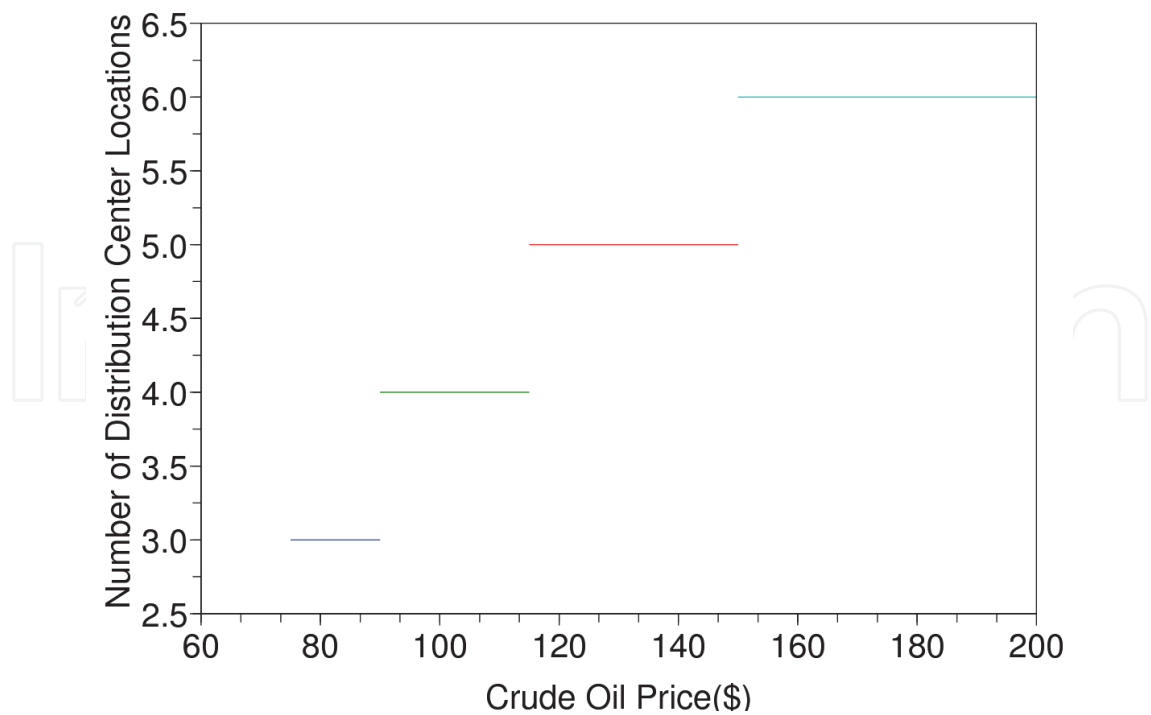

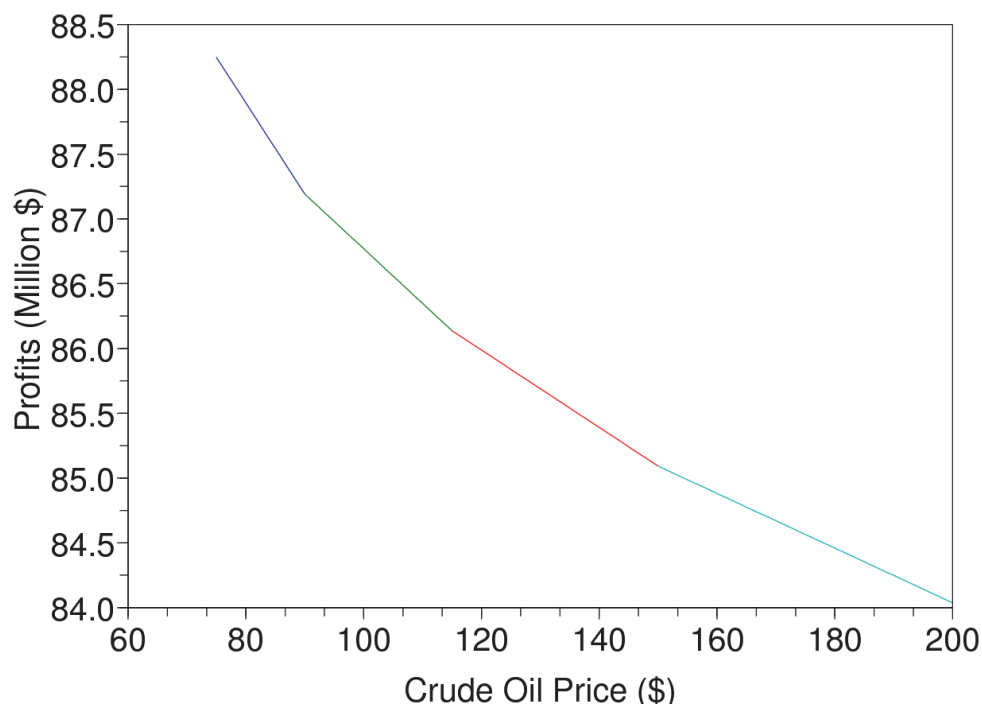
Fig. 7. Number of Distribution Center Locations

Fig. 8. Profits

prices of crude oil the profits decrease and we will open more distribution center. While we open more distribution center, it will help us to slowdown the decrease of profits.

Since we've considered different transportation modes in model (3). These modes have different transportation capacity and cost, and another key constraint come from different carbon emission. The multiple objective optimization problem, model (3), is transformed as a single objective optimization problem which can be resoled by WIT tool well, and we must balance between profits and emission. A price is suppose for each unit emission, then the minimizing emission problem can be redefined as minimizing cost problem which can be combined with the maximizing profit objective function. As described in Liu et al. (2010), the emission price can be get from the market. WIT tool can be used to optimize this combined optimization problem. Based on the model in Fig. 6, complex model divide each transportation rectangle into multiple rectangles, which correspond different transportation modes. This complex structure exceed the range limit of this paper, and we can describe the differences as follows:

• Each transportation rectangle splits into multiple rectangles which correspond different transportation modes;

• Following Liu et al. (2010), a material called emission is generated by a purchase operation, while each purchase operation has a executing cost corresponding the unit emission price.

• Each transportation operation has a unit executing cost which correspond the total fee from distance and oil price;

• Each transportation operation will consume another material called emission;

• Each product in factory is generated by a manufacture operation which will consume emissions;

With this model, emission constraints can be well integrated in our basic model. Based on the number example above, we suppose there are only two transport mode to move products from the factories to distribution centers and from distribution centers to retailers/customers. While we increase the crude oil price from 75$ to 200$, we can get the following results,
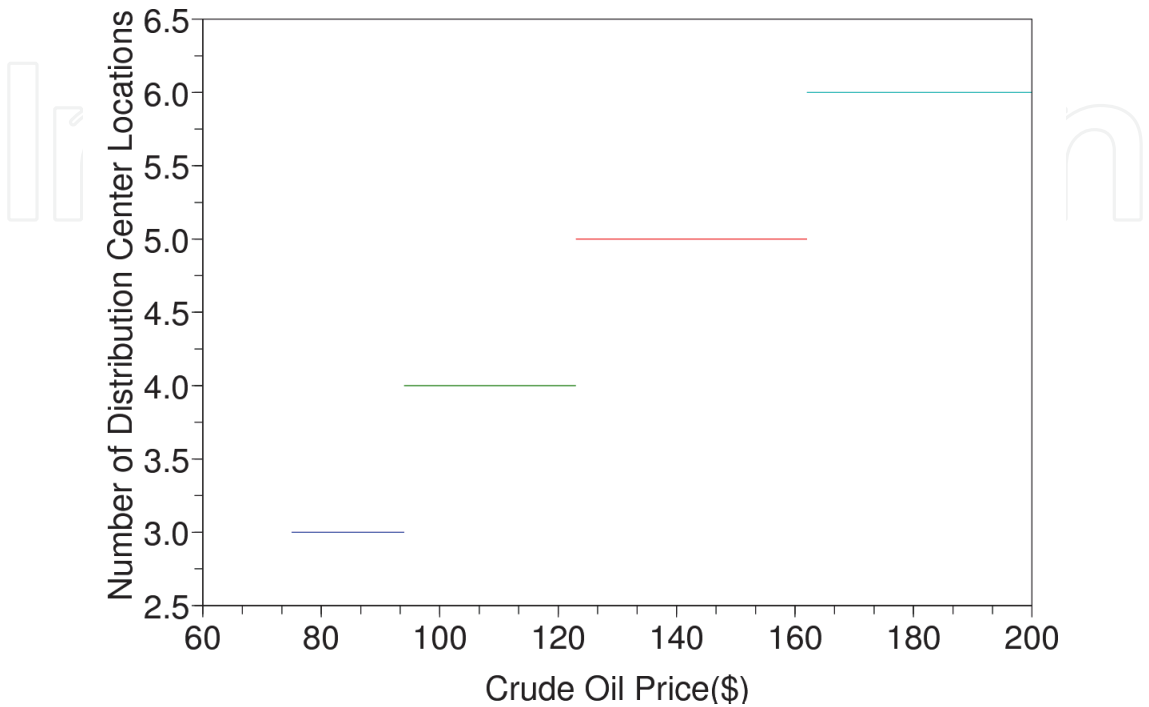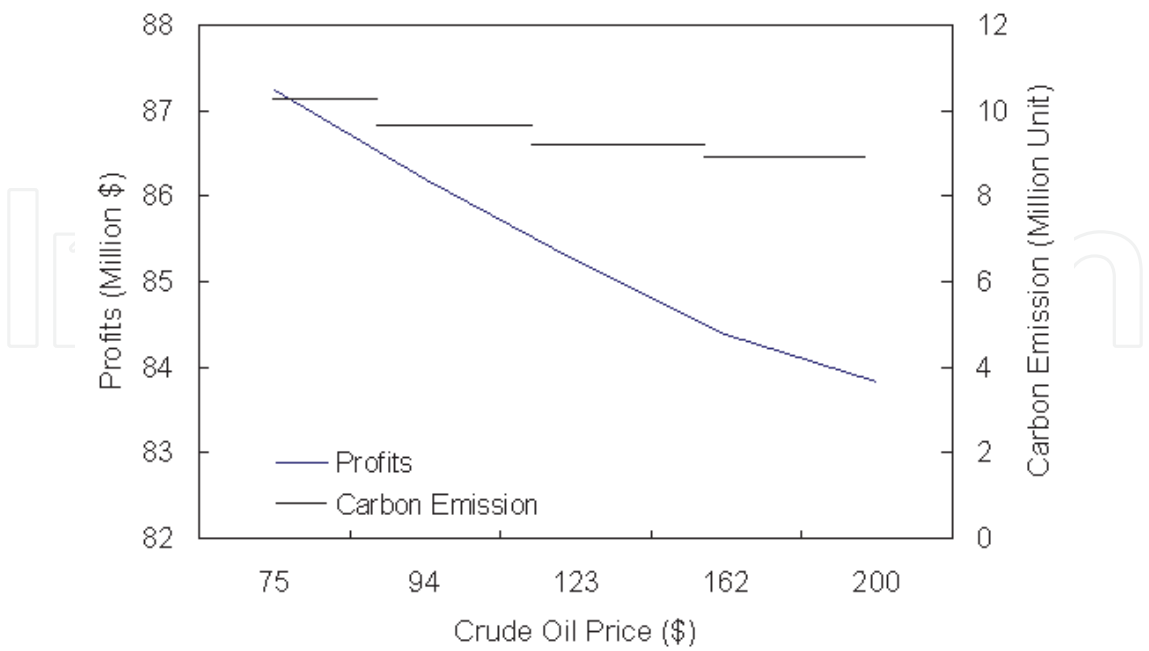
Fig. 9. Number of Distribution Center Locations

Fig. 10. Profits and Carbon Emission

1. As the crude oil price increasing, we need to open more distribution center in order to decrease the impact on the increase of the transportation cost. Compare Fig. 7 and 9 we know the factor of carbon emission will reduce the impact on the transportation cost of the increase of crude oil prices.

2. As the crude oil price increasing, the profits and the carbon emission will decrease. Compare Fig. 8 and 10 we also can get that the factor of carbon emission will slowdown the decrease of profits. Thanks for opening more distribution center we can decrease the carbon emission to some degree.

4. Conclusion

Location problem is a well established research area within Operations Research (OR). Numerous researchers and engineers have done lots of work for it. The American Mathematical Society (AMS) even created specific codes for location problems. In fact, the problem comes from industries and is created to model real problems in logistics, supply chain, city planning etc. It has played a key role in supply chain management. With the increased environment pollution concerns of people, organizations and governments, enterprises are facing pressure to protect and improve the environment, such as decreasing environment pollution, reducing waste cites and using green raw material etc. Naturally, there come the location problems for green supply chain. The objectives are to improve the performance of supply chain management and to protect the environment.

In this chapter, we firstly reviewed the traditional location problem in supply chain management from the following three views: modelling, solving algorithms and mathematical tools. Then a mathematical model is proposed to describe the distribution center location and transportation mode option for green supply chain. Based on this model, we illustrate the crude oil price impact on the distribution center location and transportation mode option by using IBM Watson Implosion Technology tool. However, there are still several issues to be studied: 1) the product supplying and demands from customer will be influenced by many factors and they always changes especially in developing countries or regions. 2) emissions from each operation are usually estimated in experiments, and more precise method must be proposed.

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Supply Chain Management - New Perspectives
Edited by Prof. Sanda Renko

Over the past few decades the rapid spread of information and knowledge, the increasing expectations of customers and stakeholders, intensified competition, and searching for superior performance and low costs at the same time have made supply chain a critical management area. Since supply chain is the network of organizations that are involved in moving materials, documents and information through on their journey from initial suppliers to final customers, it encompasses a number of key flows: physical flow of materials, flows of information, and tangible and intangible resources which enable supply chain members to operate effectively. This book gives an up-to-date view of supply chain, emphasizing current trends and developments in the area of supply chain management.

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