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Abstract

In this article, we attempt to give a comprehensive review of how classical supply chain models have evolved with advances in information technology and its related branches of knowledge. To illustrate a possible solution to meet the challenges of the present day, we propose a model of a Virtual Distribution System for a supplier (or a group of suppliers) to use in planning and operating the distribution of goods and merchandise to customers all over the entire region. These customers often demand that the products they have ordered be delivered to their preferred destinations in a highly efficient way. The modular structure of this system enables it to be more flexible and responsive to dynamic changes in the market.

Key Words: Virtual Distribution System, Information Technologies.

Résumé

Dans cet article, nous tentons de présenter une revue détaillée de l'évolution des modèles classiques de la chaîne d'approvisionnement suite à l'avancement des technologies de l'information. Pour démontrer une solution possible aux défis actuels, nous proposons un modèle de système virtuel de distribution qu'un fournisseur (ou un groupe de fournisseurs) peut utiliser pour la planification et la distribution de marchandises aux clients dans une région donnée. Ces clients exigent souvent que les produits demandés soient livrés de façon efficace à leurs destinations préférées. La structure modulaire de ce système lui permet d'être plus flexible et plus sensible aux changements dynamiques du marché.

Mots clefs : système virtuel de distribution, technologies de l'information.

1 Introduction

Recent advances in information technology (IT) have brought dramatic changes to Supply Chain Management. The traditional methods of inventory control warehousing and scheduling of deliveries for a company have to be completely revised in order to cope with the demands of customers, which have been highly complex with the advent of e-commerce and trade globalization. Centralized information on orders and inventories at warehouses (e.g., inventory levels, lead times, demands and backorders etc.) and retailers located in different regions is instantly accessible, and it can be viewed as a single virtual warehouse. This being the case, the deliveries of goods from various facilities to the customers can now be coordinated by a single management unit, and these deliveries are no longer confined to the traditional method of going from supplier to warehouses, and then from warehouses to the dedicated customers. This leads us to establish what we call a Virtual Distribution System.

2 Literature Review

Generally, virtual supply chains can be regarded as operations involving the physical and information aspects of supply chains treated independently from each other and operating in a virtual environment, such as over the Internet (Clarke, 1998). In this article, Clarke described various concepts of virtual logistics, elaborating particularly on the notions of virtual stockholding, virtual warehouses, virtual supply chains, virtual stock control, virtual trading, virtual deliveries and the substitution of trading for transport, virtual production, virtual logistics services, virtual markets, virtual growth and virtual organizations. Graham and Hardaker (2000) illustrated the potential of developing supply chain management through the Internet. Van Hoek (2001) suggested some supply chain approaches to e-business in order to create an e-supply chain to allow e-business applications to support the objectives of the supply chain. Chandra and Smirnov (2001) proposed a framework for the virtual supply chain that integrates intelligent information support, group-decision making and agreement modelling. Kotzab et al. (2003) developed an e-supply chain strategy optimization model based on the concept of supply chain management and state-of-the-art e-business.

Virtual supply chains have been applied in many areas. Ramachandran and Tiwari (2001) suggested the possibility of integrating a virtual supply chain in the air cargo industry. Ho et al. (2003) and Tatsiopoulos et al. (2002) proposed a process and methodology using virtual supply chains to improve the management of the supply chain in the clothing industry. Boyson et al. (2003) designed and developed an e-supply chain portal for the US Department of Defense to support real-time decision-making along the supply chain.

IT has significantly influenced channels of distribution in recent years and is being implemented and incorporated in the supply chain to provide a more effective way of obtaining competitive advantages (McLaughlin et al., 2003; Motwani et al., 2000; Loebbecke and Powell, 1998). In particular, virtual supply chains/logistics rely heavily on IT to share data between buyers and suppliers.

In fact, IT has come a long way in assisting supply chain management, in such aspects as word processing, spreadsheet accounts and database file operation; while communication in a traditional supply chain relies on telephone calls and faxes. Later, IT in the form of EDI was introduced to help companies exchange commercial documents, such as invoices, between business partners without human intervention, using structured, agreed-upon national and international message standards. Today, with the emergence of Internet/Intranet technology, there are many opportunities make significant improvements to virtual supply chains/logistics. The Internet/Intranet enables all entities in the supply chain to identify and coordinate the transfer of data with each other (Graham and Hardaker, 2000) and to provide just-in-time information (Alshawi, 2001). Other technology including bar coding, radio frequency identification (RFID) and global positing systems are now being used for efficient distribution and inventory management (Stough, 2001). In addition, enterprise resource planning (ERP) systems such as SAP and Baan are increasingly being used as operational IT systems to support effective supply chain management. Clearly, IT has substantially improved and supported the managing of supply chains.

The legacy systems are having difficulty fulfilling the requirements of customers. However, the adoption of advanced IT has greatly improved the order management process. Advanced IT such as computer-aided design/computer-aided manufacturing (CAD/CAM), electronic data interchange (EDI), electronic fund transfers (EFT) and multimedia assist in order fulfilment and dramatically reduce the lead time of the order flow (Gunasekaran and Nath, 1997). Various IT-aided systems (Czapiewski et al., 1999; Yu and Huang, 2001) have been designed and developed for the order-fulfilment process in supply chains. Furthermore, current purchase order processing is becoming more electronic and automatic. Shorter order-fulfilment cycle times and reduced purchase transaction costs can be achieved using e-procurement technology.

Since there has been consideration of optimization of production process and the efficient linking between the production and distribution process in a supply chain (see for example Chopra and Meindl, 2003 or Troutt et al., 2004), and there have been enterprises devoted solely to the distribution of goods to the customers, we shall confine our attention to the distribution of goods within a given network. Our objective is not aiming at developing a mathematically sophisticated complex model, but rather to focus on building a simple model that will respond to situations of market demand. By incorporating the most recent technologies in IT and artificial intelligent (AI), as well as some appropriate mathematical and meta-heuristic optimization methods, we expect this model to be sufficiently intelligent to cope with the dynamics of e-commerce market and to deliver highly satisfactory services to all customers. In the following sections, we shall describe a proposed model that will be flexible enough to apply to a variety of real distribution networks.

3 The Integrated Virtual Distribution System

We shall first consider a distribution network with p suppliers, m intermediate warehouses and n retailers, each serving a group of customers in its local neighbourhood. The regular distribution is controlled by a central unit that has immediate access to all of the information on demands from customers throughout the region including on-line orders via the Internet, inventory levels at various facilities and goods in transit between facilities. Based on this information, the central unit is able to devise a distribution plan so that all of goods will be delivered to the customers in time at minimal cost.

3.1 Our Primary Model for the Distribution Network

For simplicity, we shall consider any delivery to a customer as equivalent in cost to his nearest retailer. Any items ordered by a customer can be delivered to him from his dedicated retailer at no cost, and from any other retailer at a delivery cost equal to that from this retailer to the customer's dedicated retailer. Under certain conditions, if these items exceed a certain amount, they can also be delivered directly from one of the warehouses at a cost equal to that from this warehouse to the customer's dedicated retailer. Also, if these items exceed an even larger quota, they can be delivered from a supplier directly to the customer and the cost incurred is the same as if the goods were delivered from this supplier to the customer's dedicated retailer.

Let h_{ij} be the cost per item delivered from supplier i to retailer j,
k_{ij} be the cost per item delivered from warehouse i to retailer j,
c_{ij} be the cost per item delivered from retailer i to retailer j,
x_{ij} be the number of items delivered from retailer i to retailer j,
y_{ij} be the number of items delivered from warehouse i to retailer j,
z_{ij} be the number of items delivered from supplier i to retailer j,
m_i be the minimum amount for a direct delivery from warehouse i,
l_i be the minimum amount for a direct delivery from supplier i,
d_i be the demand of all of the customers at retailer i,
I_{Wi} be the available inventory at warehouse i,
I_{rj} be the available inventory at retailer j.

If there are no time constraints, and there is a manager who has instant access to all order information (including those customers who place their orders via the Internet, where the destination of delivery closest to retailer j can be included as the demand at retailer j,) then that manager can coordinate the entire delivery plan so that the total delivery cost is minimized. This optimal delivery arrangement can be found by solving the following integer linear programming problem.

$$
\begin{array}{lrl}
\text{Minimize } \sum c_{ij}x_{ij} + \sum k_{ij}y_{ij} + \sum h_{ij}z_{ij} & & \\
\text{Subject to} & x_{ij} + y_{ij} + z_{ij} = d_j & \text{for all } j = 1, 2, \ldots, n. \\
\text{(P)} & I_{rj} \geq \sum_j x_{ij} \geq 0 & \text{for all } I = 1, 2, \ldots, n. \\
 & I_{wi} \geq \sum_j y_{ij} \geq m_i & \text{for all } I = 1, 2, \ldots, m, \text{ or } y_{ij} = 0. \\
 & z_{ij} \geq l_i & \text{for all } i = 1, 2, \ldots, p, \text{ or } z_{ij} = 0.
\end{array}
$$

However, certain customers always specify time requirements. If these requirements were included in our model, our model may be too complex to solve instantly. One possible way of tackling with this problem is to divide customers into a few categories with different handling strategies as follows:

(i) For small quantity orders with an urgent deadline and back orders, the goods should be delivered from the nearest retailers with available stocks if the dedicated retailer happens to be out of stock.

(ii) Larger urgent orders should be delivered right from the nearest warehouse with available stocks or right from the nearest supplier if there is no warehouse with sufficient available stocks.

(iii) For normal orders, use the optimal arrangement obtained from solving problem (P). As the customers have now been divided, problem (P) has become smaller and easier to solve.

(iv) Some trucks on the road carrying goods for even more immediate delivery to customers with special requirements can be arranged to provide additional help for cases (i) and (ii).

Notice that there is no requirement for y_{ij} and z_{ij} to be multiples of x_{ij}, whereas the deliveries from suppliers and warehouses are usually in lot sizes. This is not problematic, since the remaining fractions of a whole lot obtained in the solution of (P) can either be taken from whole lots in the warehouse, from a supplier, or from the nearest retailer depending on the economics of cost and availability.

3.2 The Integrated Model

It seems that the primary model is a standard integer linear programming (LP) model that can be readily solved as a classical model. This is not the case, as the cost of delivery at each point varies with the quantity of goods to be delivered and as the distribution to various facilities changes. The cost of delivery also changes with time. If we take an average value for each c_{ij}, the solution obtained is only approximate. Thus, the final cost depends on demands from various customers at each period and on the ultimate delivery plans at

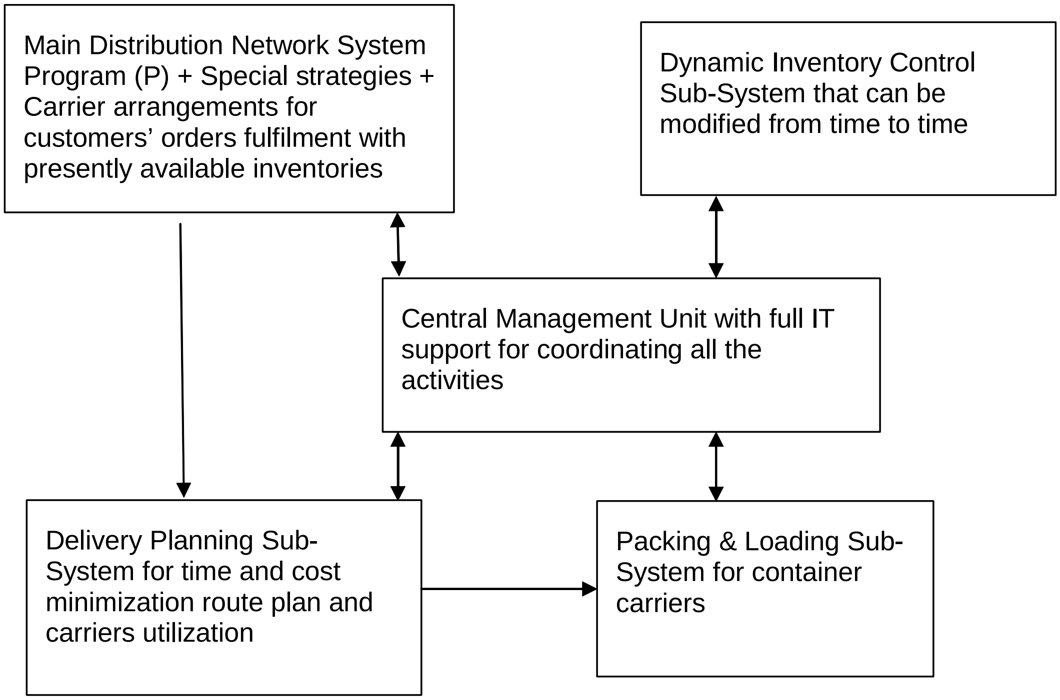

Figure 1: The Virtual Distribution Scheme

various facilities. We need to develop some sub-models integrated and interacting with the main model through the full sharing of information, so that an optimal distribution plan to truly minimize costs can be obtained. The schematic distribution scheme is illustrated in Figure 1.

We shall formulate our integrated virtual distribution model to take full advantage of all of the modern information technologies available. If more than a single item of goods needs to be distributed, some procedures for optimizing the capacity of the truck (or carrier) as well as that of the warehouses will have to be devised. These optimization procedures can be devised for different sub-models at different facilities, and then integrated with the main distribution system. Thus, before making the final delivery plan, one could obtain a near-optimal distribution schedule for each individual item separately using the above model, and then recombine them to give an initial overall distribution plan to be modified by iteration between the following distribution scheme. The following are some of the features of our proposed model:

1. The model is composed several submodels: the central distribution model, the delivery planning sub-models, the dynamic inventory control sub-models, and packing and loading sub-models. Each submodel possesses a fast optimization algorithm capable of giving an almost instant solution for each given set of input data. Iteration

between these submodels, if interfaced properly, will help to improve the solution. Even though the ultimate solution obtained may not be the true global optimum, nevertheless, it represents the best solution obtainable within an often highly time-constrained environment. A detailed description of this solution is given in Section 4.1.

2. Some random procedures such as customer insertions, deletions or exchanges like those described in Phase III of Section 4.1 can be introduced occasionally to help in the escape from a local minimum.
3. With today's state-of-the-art information technology, the effective execution of the iterative computations and the other interactions between the sub-models described in 1) should not be a problem at all.
4. Our network structure allows the computational procedures described in 1) to be carried out in parallel in most instances. This further enhances the performance in terms of speed, which is essential for our real-time application.
5. For simplicity, all of the time constraints are taken to be hard, while a soft time window can be introduced into our model without creating too many problems in solving our modified model.

As finding a comprehensive solution for the entire network, if exists, will be very expensive and time-consuming due to the enormous size of the network, our method should be a really effective alternative as far as practical application is concerned. A good lower bound, however, is useful. The one described below should be easy to compute.

This lower bound can be found by solving problem (P) on taking c_{ij}, h_{ij} and k_{ij} to be lowest possible delivery cost per unit from i to j, for all source i and destination j disregarding routing and volume constraints. (E.g., we may take c_{ij} to be the cost per unit of transporting a full truckload of goods from warehouse i directly to retailer j, without stopping over at other retailers and discarding the cost of the return of the empty truck).

3.3 Interaction between the Main Distribution Model and other Submodels

a) The interaction of the main model with the delivery sub-model is to be performed as follows:

Step 1. Output the distribution scheme to each facility, based on a predetermined set of costs "c_{ij}'s".

Step 2. At each facility or based on the information (GIS and truck availabilities), one works out the delivery plan and computes the actual costs of feeding updated values back to the main model.

Step 3. Compute the total actual cost based on the feedback from each local distribution.

Step 4. Perform procedures such as described in Phase III of Section 4.1 until there are no further improvements in the total minimized cost. .

Note. Some appropriate randomization procedures may be added to prevent the iteration process from terminating at a local minimum.

b) There are perhaps some weak links between the “Delivery” sub-model and the “Packing and loading” sub-model, especially when the arrangement of packing and loading goods may not be successfully carried out with the carriers’ capacity given by the former sub-model.

c) The changes in demand detected or forecasted by the “Inventory” sub-model and the subsequent changes in inventory policies at various facilities should instantly be reflected to the main model so that an optimal distribution scheme can be worked out taking into account these new changes.

4 Central Management Unit with full IT Support for Coordinating all the Activities

The information technology employed consists of hardware and software used throughout the main model to gather and analyse information. Highly sophisticated IT is required to provide reliable and timely information. It is used to coordinate all of the activities, especially the sharing of information. Sharing information via IT has contributed to the performance of a supply chain (Lin et al. 2002) and, thus, to a great flow of information being communicated and exchanged between each sub-model and the main model. Many years ago, EDI was the major tool for sharing information. Now, companies can use low-cost Web technology (e.g., Internet/Intranet/Extranet) to facilitate communication, collaboration, and the sharing of information either internally or externally for a relatively lower cost than in the past.

There is a variety of software packages and hardware for supply chain management. For example, ERP systems such as SAP connect not only different functions within a company via an Internet environment, but also among the company’s supply chain partners. This enables all entities to share information such as order status, product schedules and sales records, to integrate major supply chain processes.

As the complete information is instantly accessible, the entire distribution plan can be worked out effectively at the main unit as described in the previous section, where all of the required software and hardware are available. Aided by available algorithms for vehicle routing and packing and loading, a powerful meta-heuristic algorithm based on genetic searches can be developed to handle the above mentioned task within a short time constraint. A brief description of each model and of how IT supports and coordinates all of the activities is given in the following sections.

4.1 The Delivery Planning Sub-model

Effective delivery planning should connect destinations with customers at the lowest possible transportation cost within the specified time constraints. One of the analytic applications to support delivery planning is the transportation planning and content system. This system performs an analysis to determine possible methods for delivering the goods (Chopra and Meindl, 2001). In addition, global positioning system (GPS)/geographic information system (GIS) technology provides a wide range of transportation applications, including transporting routing and schedules (Ziliaskopoulos and Waller, 2000). By using GPS/GIS technology together with digital maps, trucks can obtain the most up-to-date and useful information to deliver the goods to their destination in the shortest time. In addition, Web technologies obviously have an impact on transportation management. Online containers, shipments and even transportation assets can easily be tracked (Frazelle, 2002). When delivery plans are made or modified, or shipments are not dispatched as planned, companies can communicate the changes and problems to their logistics service providers and trading partners in an automatic and faster way.

The solution obtained from our main model is the multi-source and multi-destination problem. It can also be decomposed into a number of single-source and multi-destination problems so that one can separately devise a good delivery plan at each delivery point. Depending on the quantity of goods to be delivered, the number of destinations and the time constraints, one has to determine whether one should use a single-route or multiple-route plan. We shall base our methodological study on the Capacitated Vehicle Scheduling Problem (CVRP) (See Fisher, 1995; Bramel and Simchi-Levi, 1995; and Dimitris and Simchi-Levi, 1996). The general procedure is to be performed in the following three phases:

Phase I. Determine a good lower bound for the number of carriers and an approximate number of routes:

We shall first merge customers that are sufficiently close to each other. We can make use of the classical method such as Bin Packing Heuristics to determine the best possible number of routes and carriers (or trucks) so that the total cost is minimized subject to time constraints

Phase II. Planning the Route – A simple but workable method:

We tentatively adopt Clarke and Wright (1963), saving heuristics for its simplicity and well-known reliability. For detail method is given in Clarke and Wright (1963). Further modifications, extensions or replacement by another efficient algorithm will be introduced as required.

Phase III. Refining the Route Plan:

a) Exchange customers between two adjacent routes if a further lowering of costs is possible, or insert unattended customer destinations to an appropriate route so that the cost incurred is minimized.

b) Inter-facility Exchanges: Sometimes, the deletion of a delivery to a certain customer may result in a substantial reduction in cost, while this delivery may incur only a small increase in cost when inserted in another route from another facility. This can be performed easily when full information on this is fed back from various facilities and is then instantaneously accessible from the central management unit.

The above methods serve only as a basic guild line to the development of our delivery sub-models. As the destinations change at each time of delivery, as well as the quantities and types of goods to be delivered, an optimal (or near-optimal) delivery plan needs to be obtained almost instantaneously. This plan may even be different for different times of the day. Therefore, we do need fast, but high-performing, simple algorithms, together with full IT support to achieve our goal. Furthermore, some important delivery plans at local facilities may need to be pre-designed for ultra-fast scheduling.

For one-time deliveries, there are algorithms that can minimize the number of trucks with a given capacity to handle this combination of goods to be delivered to a number of destinations visited along a certain route. A simple but practical extension is to consider the case where there are a few types of trucks whose capacities are integral multiple of the other. However, this requires the assumption that at least one truck per planned route may lead to a considerable waste of carrying space. Since the packing arrangements on carriers and subsequent routing plans are interrelated, a re-planning of the routing scheme should be carried out iteratively to minimize the total cost. For more complex cases, an integration of this module into the delivery-planning module is preferable. A careful design leading to true cost and time minimization, though difficult, should be explored.

Also, a comprehensive model should address all of the issues that arise from local situations; e.g., the geographic condition of the facilities and the available means of transportation, etc. If the distribution network is situated in a busy city like Hong Kong where a large variety of means of transportation is available, or in a region (like Pearl River Delta) where transportation can be performed conveniently by barges via water ways, then the choice of transportation mode or combination of transportation modes can also affect the cost and performance of our system. Hence, our ultimate model will be more complex and should incorporate procedures for making optimal choices leading to a further minimization of costs. Some modern meta-heuristic methods like genetic algorithms (G.A.) may help in solving this complex problem.

4.2 Packing and Loading of Goods to the Carrier's Container

Many warehouses and distribution centres have not fully automated the process of packing and loading goods to the carrier's containers. In order to speed up the process of loading and unloading goods, more efficient warehousing and material handling methods have to be employed. In order to optimize the packing space and enhance the efficiency of loading and unloading goods, more advanced IT applications or systems can be adopted. LeMaster (1990) designed and developed an expert system, namely Automated Loading

Expert (ALEX), to plan the loading of boxes into semi-trailer trucks. This system optimizes the utilization of packing space and, meanwhile, minimizes the likelihood of damage to the goods during the transition. Chua et al. (1998) implemented a simulation system that generates the packing plan visually and is able to output the image to Autocad software for printing and detailed study.

With Internet technology, a modern warehouse management system (WMS) can easily communicate with other management information systems and provide, store and report necessary information to manage the flow of products within a warehouse (Faber et al., 2002). A state-of-the-art WMS should be able to handle various functions, of which automatic packing and loading is one of the most important (Faber et al., 2002; Frazelle, 2002). Voice recognition technology/synthesized voices is becoming popular in warehouse operations. This technology has been introduced into port terminal operations to assist in the loading and unloading process (Shayan and Ghotb, 2000). Operators can speak the command to control a series of transactions, including the loading and unloading of goods. At the same time, this message is recorded for the analysis that provides a report on the position of the containers.

Recent developments in IT enable us to introduce advanced RFID and shelving arrangements for the speedy retrieval of goods. Moreover, software exists that automates dynamic storage plans for storing multiple items that can be retrieved readily.

4.3 Sub-model for Dynamic Inventory Control

An inventory control system observes demand patterns and produces a recommended inventory policy (Chopra and Meindl, 2001). With advanced IT, inventory control systems provide more accurate measures of demand at all of the retailers. The Internet enables the inventory control system to exchange information with the suppliers and, thus, to handle the replenishment of orders much more quickly. Other IT tools like bar codes and RFID facilitate the real-time updating of the goods at the point of sale. The scanned information becomes a strategic resource. This information can be further analysed using data mining techniques to forecast the demand patterns accurately and eliminate the uncertainty in demand, making it possible to manage the entire inventory more effectively.

To cope with significant changes in customer demand at various facilities in our distribution network, we should implement procedures that can modify our inventory policies from time to time according to demand. Since the demands at all of the retailers over a certain period can be computed by considering all of the planned deliveries from each retailer i over this period, an optimal reorder point can be determined as in the case of classical inventory policies. Also, the total demand from each of the warehouses can be considered as the sum of the planned replenishment to the retailers and that of the total deliveries direct to the customers; hence, optimal reorder points at various warehouses for this time period can also be determined. If an upward or a downward trend in demand at various facilities can be detected and, hence, these demands in a future period can be estimated (provided some fast and accurate forecasting method for predicting future demand is available), one can always derive a dynamic inventory policy that can automatically change from time to time so that the optimality of the overall arrangement can always be maintained.

5 Further Improvements

The structure of our model, together with the interactions between its sub-structures, have rendered the whole network highly responsive to changes in customer demand at various times and places. The planned iterations between various sub-models has helped to yield a better distribution schedule to minimize costs without sacrificing good service to our customers

As some unpredictable situations may arise, our network should be able to reconfigure itself easily, so that the distribution process is again optimized. This calls for some really fast algorithms to find the best and the most effective changes that can be made in the network (e.g., some repositioning of warehouses and outlets) to achieve this purpose.

Furthermore, if full information on all goods in transit as well their locations can be obtained through an advanced GIS, further minimization of costs and time is possible by elaborating the model described above. For example, goods that are carried by trucks may be redirected to a different destination to fulfill an urgent demand by a certain customer. A decision support device that will help with rescheduling to achieve this is to be incorporated.

Recent advances in cellular-based tracking and tracing technology can help to overcome the drawbacks of GPS and is less expensive to implement. We propose the use of this method, as it is most suitable for newly developed and densely populated regions like the Pearl River Delta, in China's sub-tropical south, connects three of the Far East's most exciting destination—Hong Kong, Macau and Guangdong province.

It is essential that we provide a platform for combining data on demands, customer orders, inventory levels, and so forth obtained from various sources including the Internet for the central management responsible for coordinating the distribution. Efficient methods should be employed or developed to regroup, classify or even analyse such data to render it usable for development and operation at various phases of our distribution network. For example, the management needs to know (almost online) all of the demands to be delivered to various destinations today. Besides, one should continue to explore every possible means of extracting all of the benefits to be had from fully integrating IT into the distribution system.

6 Conclusion

We have described an integrated Virtual Distribution Model that takes full advantage of state-of-the-art IT systems. This model is quite flexible and can be adapted for use in any specified distribution network as required by global suppliers. This model can be implemented so that the regular distribution operations can be performed in the most cost-effective manner.

The modular structure of this model allows for easy modification. For example, in a country or region that is very densely populated with major cities at different degrees of modernization, like the Pearl River Delta in China, a special feature of this vast distribution network is that the means of transportation ranges from very primitive to very modern. In some of the well-developed sub-regions, multi-modal transportation choices are available. There must be some strategic choices to optimize its performance.

One notices that detailed descriptions of some of the sub-models have intentionally been omitted. It is expected that the most suitable well-known methods or some new methods will be employed so that they can best be applied to particular distribution systems. Our distribution scheme only provides a general framework and some efficient and versatile procedures. Further developments in an expanded virtual supply chain that includes the producer(s), are to be investigated. It is hoped that a full Virtual Supply Chain Model that can be applied to certain important trading zones will be developed.

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