MULTI-ITEM TWO-ECHELON INVENTORY-DISTRIBUTION SYSTEM DESIGN : A CASE STUDY

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This is to certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

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In this study, inventory–distribution system of a company operating in Fast Moving Consumer Goods (FMCG) industry is analyzed. The system is a multi–item, two-echelon, divergent inventory–distribution system with transportation constraints. The warehouses in the system are nonidentical and all of the warehouses are allowed to hold stock. The goal is to achive target customer service levels. Throughout the system, inventory is controlled by echelon stock periodic review (R, S) order-up-to level policy. The problem is the determination of inventory control parameters in the system and effective replenishment of the inventories of many items at regional warehouses under transportation constraints. An approach consisting of three modules operating in a hierarchy is developed to manage the system. The approach calculates the inventory control parameters of the items (order-up-to levels at the regional warehouses and stock allocation fractions); determines the replenishment periods of the items with the objective of balancing the vehicle requirements among periods and performs the daily replenishment of inventories minimizing the maximum deviation from the inventory policy under transportation constraints. A heuristic approach is adapted from the literature for the inventory control parameter determination part of the approach; an IP model is formulated for the replenishment period scheduling part and a MIP model is constructed for the replenishment process. The proposed approach is simulated with retrospective data of the company and compared with the existing system in the company, in terms of the performance measures defined. Satisfactory results are obtained with the proposed system.

Keywords: Two-Echelon Inventory System, (R, S) Policy, Multi-Item, Periodic Review, Distribution

ÖZ

ÇOK-ÜRÜNLÜ İKİ-KATMANLI ENVANTER-DAĞITIM SİSTEMİ TASARIMI : BİR VAKA ÇALIŞMASI

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Bu çalışmada, hızlı hareket eden tüketim malları sektöründe faaliyet gösteren bir şirketin envanter-dağıtım sistemi analiz edilmiştir. Bu sistem taşıma kısıtları olan çok ürünlü, iki katmanlı, ıraksak bir envanter-dağıtım sistemidir. Sistemdeki depolar birbirinden farklıdır ve bütün depolar stok taşıyabilmektedir. Amaç, hedeflenen müşteri hizmet seviyesine ulaşabilmektir. Sistem genelinde periyodik gözden geçirme (R,S) maksimum stok envanter politikası uygulanmaktadır. Bu çalışmada ele alınan, envanter kontrol parametrelerinin belirlenmesi ve taşıma kısıtları altında bölge depolarındaki ürün envanterlerinin, envanter politikasını en az bozacak şekilde yenilenmesi problemidir. Sistemi yönetebilmek için hiyerarşik bir şekilde çalışan ve üç modülden oluşan bir sistem geliştirilmiştir. Bu sistem, tüm ürünler için envanter kontrol parametrelerini (bölge depolarındaki maksimum stok seviyeleri ve stok tahsis oranları) hesaplamakta; zaman birimleri (günler) arasındaki kamyon gereksinimini dengeleyecek şekilde envanter yenileme (gözden geçirme) periyotlarını belirlemekte ve taşıma kısıtlarını ürün-bölge deposu ikililerine adil bir şekilde dağıtarak günlük envanter yenilemelerini gerçekleştirmektedir. Bu sistemin envanter kontrol parametrelerini hesaplama modülü için literatürden bir sezgisel yöntem uyarlanmış, yenileme periyodu belirlemesi ve taşıma kısıtlarını tahsis etme modülleri için ise iki

optimizasyon modeli yazılmıştır. Önerilen yaklaşım geçmişe yönelik verilerle test edilmiş ve elde edilen sonuçlar şu anda kullanılmakta olan sistemle karşılaştırılmıştır. Önerilen yaklaşımın, sistem için belirlenmiş performans ölçütleri açısından, başarılı sonuçlar verdiği görülmüştür.

Anahtar Kelimeler: İki Katmanlı Envanter Sistemi, (R, S) Politikası, Çok Ürün, Periyodik Gözden Geçirme, Dağıtım

To my parents, my sister and my love…

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CHAPTER 1

INTRODUCTION

In this thesis the inventory-distribution system of a fast moving consumer goods (FMCG) company is studied. The company produces biscuits, cakes, crackers, chocolates and bars. Products are sold at 200,000 sales points, dispersed all around Türkiye.

The supply chain of the company consists of 182 suppliers, 4 manufacturing plants, 8 regional directorates, 148 distributors, approximately 182,000 retailers and 60 chain markets which have 1200 sales points. Effective management of such a huge supply chain is a key success factor for the company to strengthen its place in the industry and increase its market share.

Starting with the beginning of year 2004, the company decided to redesign its distribution network in order to reduce high logistics costs, increase the effectiveness of its production plans by getting consolidated demand data and increase the service level to its customers (distributors and chain markets). The distribution network design studies resulted with 6 regional warehouses, located between the production plants and the customers of the company. The new network design reduces the logistics costs at a considerable amount, as a result of the consolidation of demand at the regional warehouses and making palletized high volume shipments (with high capacity trucks) possible.

Network design is a strategic level decision and affects the tactical and operational level decisions and systems as well. Those systems should be redesigned on the backbone determined by the network.

Locating regional warehouses between the customers and the plants of the company changes the single-echelon network to a two-echelon network, in terms of finished product flow between the company and the customers. Therefore there is a need to adapt the inventory control system to the new two-echelon structure and redesign the distribution system considering the replenishment of the stocks at the regional warehouses.

Two-echelon systems generally consist of a central warehouse supplied by a supplier and a number of regional warehouses or distribution centers supplied by the central warehouse that fulfill the demand of the customers.

Determining inventory control policy is the most vital part for the operation of a two-echelon inventory system. The inventory policy to be applied and the stock allocation methods among the second echelon stockpoints are studied by many researchers for single-item cases. Different solution approaches and operating principles are proposed under various assumptions.

The literature in this area generally differs in terms of the review policy (periodic or continuous), the objective of the inventory system, cost minimization or target service level attainment, intra-echelon product flow availability and allowance for central stock. However, there are only a few studies in the literature that consider the multi-item case. Generally, the available ones are either for service parts inventory management with continuous review policy and Poisson demand or for vehicle routing or network design problems. Moreover, the studies in the literature on multi-echelon inventory systems do not consider any constraints. It is assumed that no capacity constraints exist for production, storage and transportation. Especially the transportation constraints make the replenishment process more complicated and in the case of multiple items, meeting the inventory policy requirements is not always guaranteed.

The inventory-distribution system considered in this study has a multi-item, two-echelon, divergent network structure with no production and storage capacity constraints but has some transportation constraints. The review policy is periodic and all of the stockpoints are let to hold inventory. The objective is the target fill rate attainment.

In the study, an inventory-distribution system is designed for the management of the two-echelon structure described above. Transportation constraints could not be integrated into the inventory control parameters determination. Instead, the proposed system consists of three modules operating in a hierarchical manner. First module, calculates the inventory control parameters by a heuristic adapted from the literature. The second module groups the items according to replenishment (review) schedules by an IP model, with the objective of balancing the truck requirements among periods (days). The aim is to minimize the required number of trucks and use these trucks with high utilization. The third module determines the optimal vehicle allocation and order replenishments under the transportation constraints, minimizing the violation of the inventory policy that is determined by the first module. The third module is formulated as a MIP model. The first module is coded in MATLAB 7.0 and the optimization models for the second and third modules are coded in GAMS.

The proposed system is simulated with the retrospective data of the company in order to see its effects on the system and compare the results with the actual results of the current system, in terms of the performance measures defined for the inventory-distribution system. Two simulation runs of the proposed system are performed: in the first one, the proposed system is simulated without the transportation constraints, while in the second run, the transportation constraints are considered. Results obtained from the two simulation runs are discussed and compared with the actual results in existing system. It is seen that, with the proposed two-echelon system, in which there are regional warehouses between the company and its customers, the total logistics cost of the company decreases and the customer service level, expressed with fill rate and response time, improves. The main drawback is the robustness of the system in terms of the fill rate attainment, which is caused by the nonuniform demand distribution throughout a month, as a result of the incentive system used for the distributors of the company.

The thesis consists of six chapters, which are organized as follows:

In Chapter 2, the problem definition and the scope of the study is given. The existing inventory-distribution system and the related problems are stated. The proposed system is explained; the problem environment and the scope are defined. Chapter 3 includes a review of the literature on general multi–echelon and two–echelon inventory systems. In Chapter 4, the solution approach to the stated problem is defined. The proposed inventory–distribution system, consisting of three modules operating in hierarchy is explained. Mathematical models and algorithms for these modules are presented. In Chapter 5, the simulation of the proposed system with retrospective data is described and the results obtained by this simulation are discussed. The proposed system is compared with the existing system in terms of the performance measures. Finally in Chapter 6, the study is concluded and suggestions for future research are given.

CHAPTER 2

PROBLEM DEFINITION AND SCOPE OF THE STUDY

In this chapter, current inventory-distribution system of the company and the problems inherent in the system are explained. Then a logistics network structure for the company is proposed and its expected benefits for the company are stated. Finally the scope of the study is discussed in detail.

2.1 Current System and the Problems

Current inventory-distribution system from the plants to the distributors and chain markets can be described as a multi-item, single echelon system. The customers of the company are the distributors and the chain markets that are directly served from the plants. Inventory is held at the plants' warehouses. Plants are dedicated to different product families. Each plant holds inventory of its finished goods only in its own warehouse that is located nearby, except the biggest plant the warehouse of which is the central warehouse. In this central warehouse there are dedicated storage areas where the products of other plants are stocked as well. Customer orders include a number of different products produced at different plants. The purpose of the stocks in the central warehouse is to prevent the trucks from travelling among the plants to pick up the goods ordered by the customers. Based on the historical customer orders data, 70 % of the orders contain goods from four different plants. If the amount of stock for the goods of other plants is sufficient in the central warehouse to meet the requirements of customer orders, the truck is totally loaded in the biggest plant, i.e., central warehouse. However, if the stock level is not adequate to meet the amounts ordered, the truck has to visit the other plants and collect the products from their own warehouses. Since the capacities of these stocking areas dedicated to other plants' goods are not sufficiently large, they do not serve the purpose intended.

The process of truck loading is also very inefficient. The trucks are loaded with parcels. Palletized shipment is not possible due to the demand compositions and physical availabilities of the distributors. Since shipment is not made on pallets, the loading process using parcels takes a very long time compared to loading with pallets. This makes the travel of trucks among the plants and picking up goods at different plants even more problematic.

There are also small sized depots at the sites of the seven of eight regional directorates of the company, which are geographically dispersed in Türkiye. However, these depots are not used as distribution centers. They are used only to fulfill the urgent demands of the distributors, which are very low in amount, and the demands of the chain markets that are usually less than a full truckload.

Customers place their orders daily to the regional directorates of the company. Regional directorates direct these orders to the 'shipment department' after the necessary adjustments are made. Orders are processed, routes and truck loads are formed by the shipment department.

Direct shipment from the plant warehouses to the customers is made by a third-party carrier company that operates a dedicated fleet of trucks for the company, each having a net loading capacity of 36 m^3. Shipments' payment to the carrier company is made on the basis of total distance travelled (YTL/km), regardless of the amount of load carried. Because of this payment scheme, shipments are made in full truckload. Distance is calculated as the total length of the route from the warehouses to the customer and from the customer back to the warehouses. This means that the company pays for the empty trucks coming back from the customers. The kind of trucks used are expensive modes of shipment, in terms of the loading capacity and fuel consumption. Cost per volume carried per distance travelled is higher than using bigger and higher capacity trucks. Customers of the company are dispersed over

Türkiye. Shipment made in such a large area with an expensive mode of transportation increases the transportation costs of the company. Moreover the response time to the customers is very long. Some orders are delivered 3 days after they are placed. Since shipments are made from a single point (plant warehouses), some customers fall more than 1000 km. away from the plant warehouses.

Other problems in the current inventory-distribution system of the company arise from the forecasting and incentive systems being used. Forecasts are based on the total sales target for the year which is determined at the end of the previous year by the top managers of the company. Then this total amount is divided into months and distributed among the sales regions according to the sales potentials of the regions. These targets are not in terms of SKU, but in terms of the total weight. Monthly total sales targets for the following three months are sent to the regional directorates every month. Regional directorates partition the total monthly amounts among the distributors and chain markets. Finally distributors and chain market managers get the total amount they should sell for the following three months. They split these total amounts into 30 product groups which constitute all the SKUs of the company according to past sales data. These product group sales targets are consolidated at the regional directorates and finalized after necessary adjustments. Those approved amounts become the monthly sales targets of the distributors in terms of product groups. The distributors are then asked to split the product group targets among the SKUs of each group as forecasts. Those SKU-based forecasts are consolidated at the 8 regional directorates and sent to the marketing department. Marketing department combines the monthly forecasts that come from the sales regions and splits them into weeks using some multipliers determined according to the customer order patterns in a month. While splitting these amounts, promotional and advertisement activities are also considered; hence some small amounts are added to the calculated forecasts. This means that the total of weekly forecasts for a month for an SKU is always greater than the total sales target of that SKU for that month. Every week, weekly forecasts of the following twelve weeks are sent to the production plants as weekly production orders on a rolling horizon basis. Poduction order of an SKU for a specific week can be revised ten times (revision is not allowed in the last week) with narrowing limits as the specific week becomes closer. Production plants make 12-week production plans on a rolling horizon basis every week, using these weekly production orders as input. While making the plans, the main objective is to fulfill these production orders. Based on the historical data, on the average, plants can meet 95% of these orders on time. Apparently the system operates as a “push” (forecast driven) system. There are mainly three problems here. Firstly, the review and planning periods are not synchronized between the production plants and the sales organization. Production plans are made weekly, however the sales targets are monthly. Monthly production is almost uniformly distributed among the weeks of a month, but the majority of the orders from the distributors come during the last two weeks (mainly the last week) of the month. Secondly, monthly total of the production orders is always greater than the monthly sales targets. Thirdly, although the production orders are fulfilled in SKU basis, distributors get incentives when they realize their product group sales targets. Group-target realization based incentive system causes imbalances in terms of sales among the SKUs that constitute the product group. As a result SKU-based weekly production orders and weekly customer orders match each other with a ratio of only 65%.

These three problems discussed above give rise to high safety stocks and cycle stocks in the production plants. However, the average fill rate of the customer orders is still 90% for the year 2005. The fill rate turned out to be even worse in the previous years.

2.2 The Proposed Logistics System

By the year 2004, with the changes that occured in the market and in the economy, the company decided to develop strategic plans for the years ahead, when the rules of the game are expected to be much more different. It was realized that to be successful in the competition; cost minimization, service level maximization and product and process differentiation become more important. Especially service level improvement in every echelon of the supply chain in FMCG industry is more crucial than any other industries. Production costs could no longer be reduced, as every effort to reduce production costs has already been made by all of the companies in the industry. Logistics, then, seems to be the most promising area for cost reduction and process improvement. What's more, the customers are becoming more demanding day by day. They want to carry less inventory than before, as holding inventory is no longer profitable as it used to be; instead the customers prefer to be closer to the production plants so that their requirements can be met within a shorter lead time. Moreover chain markets want their shipments to be made on pallets. As a result of all these, the company has started a project in the field of logistics.

Bulur and Çölova (2004) has shown that when the logistics network is redesigned by the opening of six regional warehouses (distribution centers) between the company and its customers, logistics costs can be reduced by a considerable amount, while the response time to the customers is shortened. They have extended the location-allocation model developed by Güler et.al. (2004) and found out that logistics costs can be significantly reduced when six regional warehouses are opened. In this model, the direct shipments from the plant warehouses to the regional warehouses are made by the high-capacity trucks; and products are shipped on pallets in the trucks. Currently outbound shipment from the regional warehouses to the customers is made by the smaller trucks and no pallets are used. Regional warehouses serve the customers in their service region. Each customer is served by only one regional warehouse that it is assigned to. Cost reduction comes about mainly from using high-capacity trucks that carry full truckloads between the plants and the regional warehouses, enabling the shipment of the products over a considerable length of the route by a cheaper transportation mode. Although warehouse operating costs increase with the addition of six regional warehouses, the reduction in the transportation costs outweighs the increase in the warehouse operating costs.

When the logistics network is redesigned in the proposed manner, the company becomes closer to its customers and obtains the chance to deliver their orders within shorter lead times. This is expected to increase the customer satisfaction and also to decrease their stock levels. Besides, palletized shipments can be made to the chain markets, in response to their requirements, as products can be carried on pallets from the plants to the regional warehouses in the proposed system. Since loading operations take much less time when products are loaded on pallets, the travel of trucks among the plant warehouses may not be as problematic as it is currently.

Normally total inventory of a company increases when an additional echelon is added to its logistics network and stocks are decentralized. However, Bulur and Çölova (2004) claim that total inventory may decrease if the appropriate inventory replenishment policies are applied and the push principle is changed to the pull principle (demand driven) in the proposed two echelon system. They also insist that by consolidating the orders at the regional warehouses, the total variation in the orders up in the supply chain –bullwhip effect– may be decreased and together with the pull system this may increase the effectiveness of the production plans by generating more reliable inputs as the production orders.

2.3 Scope of the Study

Prior to this study, the decisions already made in the context of the logistics project in the company are the followings:

- the locations of the regional warehouses,
- the assignment of the customers to the regional warehouses,
- the type of vehicle to be used for the shipments from the plant warehouses to the regional warehouses,
- the type of vehicle to be used in customer order shipments from the regional warehouses to the customers.

The remaining decision problems to be solved before implementing the proposed system are the followings:

- the inventory policy to be used in the new two-echelon logistics network,
- the method to compute the inventory control parameters,
- the number of trucks needed and the method for the replenishment of the inventories at the regional warehouses.

This work aims to complete these missing parts in the proposed logistics network and to verify the expected benefits in terms of inventory holding cost, transportation cost, response time, service level and production order-customer order match.

The inventory-distribution system studied has got the following characteristics:

- multi-item system with almost 200 SKUs produced and distributed
- each plant producing its own SKUs; each SKU being specific to one plant only
- no capacity problem for the plants
- each plant's warehouse acting like a central warehouse for its SKUs
- two-echelon network from the inventory point of view and a single-echelon network from the logistics point of view. There are six regional warehouses and one virtual central warehouse which is like the combination of four production plants' warehouses
- an arborescent network in which each location has got a unique supplier
- regional warehouses that serve only the distributors and chain markets in their service area and act like distribution centers between the plants and its customers
- demand at the regional warehouses consisting of the daily orders received from the distributors and chain markets operating in their service area
- independent demand across regional warehouses
- stochastic demand per period at the regional warehouses
- seasonality in the demand, for all SKUs following the same pattern
- unmet demand backordered

The schematic representation of the system can be seen in Figure 2.1.

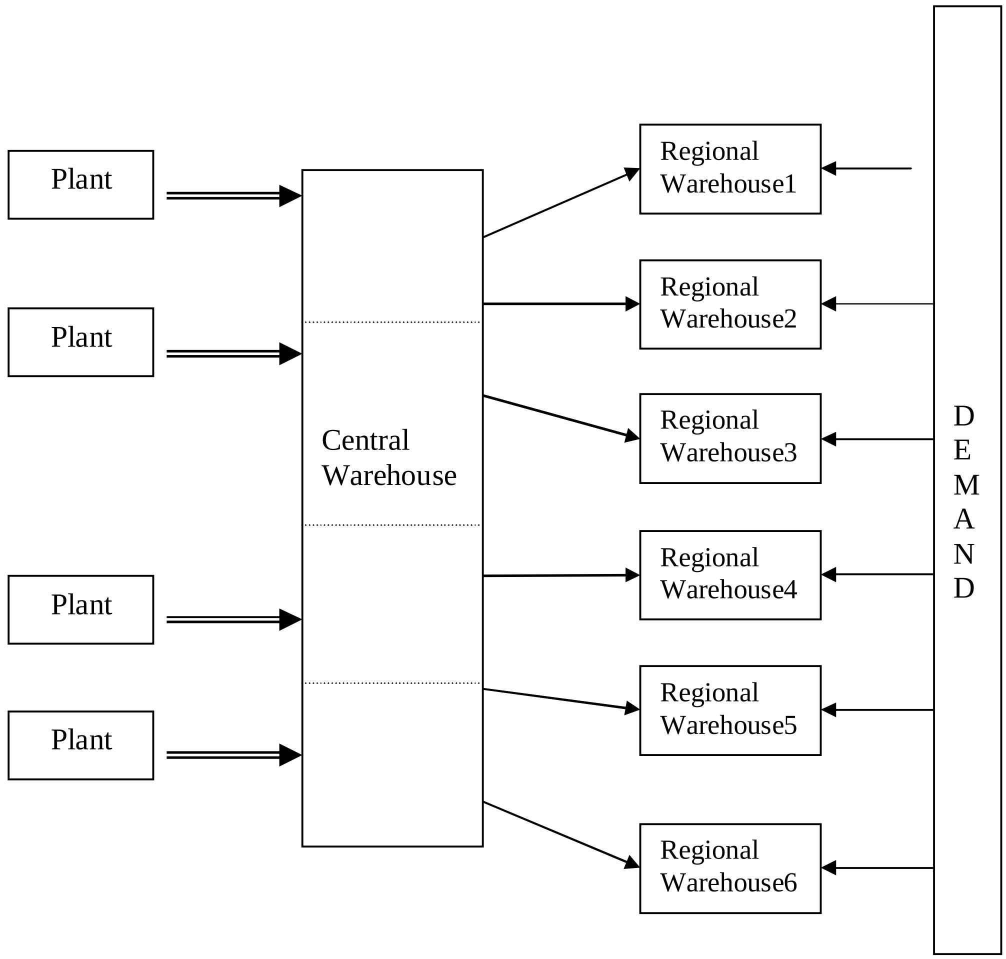

Figure 2.1. Schematic representation of the system

Echelon stock policy is chosen in inventory control in order to reduce the bullwhip effect faced by the production plants and to change the system to a pull structure. The echelon stock of a stock point is the sum of its physical stock <u>plus</u> the amount in transit to or on hand at its downstream stock points <u>minus</u> backorders at its end stock points. Furthermore, the echelon inventory position of a stock point is the echelon stock of the stock point <u>plus</u> the amount in transit to it.

Regional warehouses and the central warehouse are both allowed to hold inventory, however, the central warehouse does not face external demand, but allocates the available inventory to the regional warehouses. Inventory in the system is controlled by a periodic review, echelon stock (R,S) order-up-to level inventory policy. Review period, R, is one week, in accordance with the production plans used in the plants. Every R periods the echelon inventory position of the central warehouse for each SKU is checked, and orders are placed to the plants to bring the echelon inventory level of every product to its order-up-to level S. The orders placed by the central warehouse to the plants are used as the inputs for the production plan. These orders are received by the central warehouse after a fixed lead time and allocated to the regional warehouses to bring the inventory level of every SKU at each regional warehouse to its specific order-up-to level S. There is also a fixed lead time between the central warehouse and regional warehouses. The lead time can be different for every regional warehouse. Lead time to the central warehouse is the same for all plants. Lateral transshipment among the regional warehouses is not allowed, since the distance between the regional warehouses and central warehouse is shorter than the distance between regional warehouses.

The allocation process between the central warehouse and the regional warehouses is affected by two important factors: the availability of the physical stock at the central warehouse and the logistics system constraints.

Stochasticity in the demand of customers changes the available stock levels at the central warehouse during the replenishment (review) times. If the physical stock of an SKU at the central warehouse is sufficient to raise the inventory position of that SKU at each regional warehouse to its corresponding order-up-to level, the required amounts are passed to the logistics process as the orders of the regional warehouses. However, if the physical stock is not sufficient to satisfy all of the requirements, the available stock is rationed among the regional warehouses. Rationing is done according to the rationing parameters determined for each regional warehouse. These rationing parameters which are non-identical for each SKU add up to '1'. Rationed amounts are used as the orders of the regional warehouses in the logistics process.

Logistics process of the system assumes that there is no routing between regional warehouses. The distances between the regional warehouses are more than the distances between the plants and regional warehouses. Also there is a limitation for the number of trucks that can be loaded from a plant during a day and the trucks must go with full truckload. This is because transportation costs are much higher than inventory holding costs in this industry. When past years' cost figures are examined it is seen that yearly inventory holding cost equals approximately 40% of the yearly transportation cost. Also the regional and central warehouses belong to the same company, there is no difference in holding the inventory at the plant warehouses or at the regional warehouses. Required number of trucks should be minimized and trucks should be used with high utilization rates. Another important aspect is that demand of the customers is in units of parcels. However, the shipment unit from the plant warehouses to the regional warehouses is a pallet size. SKUs are stored on pallets at the regional warehouses. Because of the restrictions that come from the logistics system, amounts sent to the regional warehouses are not always exactly equal to the order amounts determined according to the stock availability and inventory policy. As a result, according to the situation, the shipment amounts to the regional warehouses can be more or less than the required amount. But the deviation from the optimal amounts is tried to be minimized.

To summarize, the inventory-distribution system under consideration is a multi-item two-echelon, divergent network, operating with a periodic review, echelon stock (R,S) order-up-to level inventory policy, with no production and storage capacity constraint but where transportation constraints exist and any unmet demand is backordered.

General literature on the multi-echelon or two-echelon inventory systems do not consider the multi-item cases and do not include a transportation constraint. In the presence of transportation constraints with multi-item distribution, distribution coordination and load consolidation becomes very important. These factors affect the application of the optimal inventory policies. Therefore, the main objective of this study is to find the optimal inventory control parameters for the network and design a system that minimizes the deviations from the optimal policy under different constraints.

The inventory-distribution system design in this study consists of three modules operating in a hierarchy. First module determines the inventory control parameters of the system. Second module groups the SKUs and assigns them the review (replenishment) days, such that the truck requirement throughout a week is balanced and the utilization of the trucks is high. Second part also calculates the minimum number of trucks required in a day to operate the system. Third module consolidates the orders, assigns them to trucks, allocates the trucks to the regional warehouses and plant warehouses under available truck capacity and transportation constraints while minimizing the deviation from the optimal inventory policy. The figure showing the interactions between the modules can be seen at the end of Chapter 4, where the modules are detailly explained.

First and second modules of the inventory-distribution system are tactical level decisions performed once a year or a season according to the demand pattern changes accross SKUs and regions. The module that constitutes the third part works every day. Both the constraints and the decisions at this level are operational.

CHAPTER 3

LITERATURE SURVEY

Multi-echelon inventory models are widely studied in the literature. There are different types of networks and inventory control methods investigated in this area. In this chapter, some of the literature restricted to multi-echelon, periodic review, divergent inventory systems, is summarized in accordance with the system considered in this study.

There exists a great number of studies in the literature that focus on the cost minimization as the objective while determining the inventory control parameters. Generally, service level obtained as a consequence of the inventory policy is taken as a secondary performance measure in these studies. Also most of the researchers evaluate the performance of their method by applying a simulation study at the end of their work.

Eppen and Schrage (1981) study a two-echelon divergent network using an extreme push control policy. This two-echelon system consists of a depot and n warehouses. The depot implements a periodic review, echelon-based (m,y) policy in which every m periods the system inventory position is raised to a base stock of y. The depot is not allowed to hold inventory. After receiving a new shipment, the depot rations it to the warehouses so as to maintain all inventories at a balanced position. This means that all warehouses have the same stockout probability at the end of the lead time plus the review period m. Assuming that all end stock points have identical parameters (holding and penalty costs, lead time) and face independent identically distributed normal demands, they model the stochastic behaviour of the end stock points (warehouses) inventory. An important assumption made in their study is the

‘Allocation Assumption’ which implies that, each time an allocation is made, the depot receives enough material from its supplier to be able to allocate the material to each warehouse so that an equal fractile point is achieved on an appropriately chosen demand distribution. The phenomenon of not being able to achive this is reffered to as ‘imbalance’. This assumption is also used by the other researchers. They derive approximately optimal policies and costs of (1) a base stock policy at the depot, assuming no fixed order costs, and (2) an (m,y) policy at the depot, assuming fixed order costs at the depot. They apply a cost minimization perspective.

Bollapragada et al. (1998) extend the work by Eppen and Schrage (1981). They allow the warehouses to have different parameters, which is the relaxation of one of the restricting assumptions made by Eppen and Schrage (1981). This means that in their study the warehouses are non-identical. Other assumptions still hold. They derive a closed form expression for the base stock level and present a simple and easy to implement allocation policy at the depot. At the end of their study, they evaluate the accuracy of their allocation and ordering policies, by obtaining the average costs incurred at the warehouses through simulation. The simulation results show that the suggested policy performs very well.

Diks and de Kok (1998) determine a cost optimal replenishment policy for a divergent multi-echelon inventory system under periodic review order-up-to policies. Every stock point is allowed to hold inventory. The differentiating part of their study from the previous ones is that the demand distribution need not be normal. The objective in their study is to minimize the average holding and penalty costs at the end stock points per period in the long run. They prove that a decomposition approach can be used to deal with divergent N-echelon systems, given the balance assumption. Balance assumption, as defined by Verrijdt and de Kok (1995), assumes that the rationing policy always allocates non-negative stock quantities. They reduce the complex multi-dimensional problem of determining the cost optimal policy, to the problem of seperately determining the optimal order-up-to level at every stock point and the optimal allocation functions to its successors. The analysis shows that the optimal order-up-to level can easily be determined by solving a one-dimensional problem closely resembling the classical newsboy problem. They also derive several properties which lead to an algorithm to determine the optimal allocation functions and a classification scheme of optimal allocation functions. Although the procedure they propose gives exact results, the determination is cumbersome and time consuming.

Diks and de Kok (1999) develop a more approximate approach to determine a replenishment policy that is almost cost optimal, but easy and fast to be used in practical applications using linear allocation functions. An algorithm is developed to compute the order-up-to level and its allocation fractions so as to minimize the expected total costs as much as possible. The algorithm is tested by a simulation study on a three-echelon system and it turns out that the algorithm performs well.

Erkip, Hausman and Nahmias (1990) extend the Eppen and Schrage's (1981) model to the case of correlated demands. They allow the item demands to be correlated both across time and across warehouses. The depot does not hold any inventory in their model. They obtain a conceptually simple newsboy-type result for the determination of systemwide safety stock, using the Allocation Assumption and the Coefficient of Variation Assumption which states that, for any item, the coefficients of variation of demand at the warehouses are equal. Numerical evaluations of their analysis show that correlations in the demand cause larger amounts of safety stock for optimal control compared to the non-correlated demand situations.

Other than the cost minimization perspective, some reserachers in the multi-echelon distribution systems literature, take service measure at the end stock points as the objective, in determining the inventory control parameters of the multi-echelon divergent systems. The researchers that use fill rates constraints instead of cost minimization, relax the constraint of normally distributed demand in the end stock points. Their techniques can be used with any demand distribution.

Verrijdt and de Kok (1996) study the determination of the echelon order-up-to level at the central depot in order to ensure that the demand satisfied from stock on hand at the end stock points equals to a predetermined target level, in a two-echelon network. The target levels do not have to be equal in the end stock points. The central depot is not allowed to hold stock and works only as an allocation center. By allowing different stockout probabilities, they generalize the concept of imbalance and define it as the occurence of negative allocation quantities after application of a straightforward allocation policy. This makes possible to determine echelon policies that satisfy target service levels under any service criterion. They also derive analytical approximations for the probability of a negative allocation to a particular stock point as an indication for the probability of imbalance. They present an ordering and allocation policy which is based on a decomposition approach. While the results of the algorithm are only approximations, these can be obtained very fast and yield excellent results. Moreover two adjustment methods which improve the service performance considerably in certain cases are presented.

van der Heijden (1997) determines a simple inventory control rule for multi-echelon distribution systems under periodic review without lot sizing. He focuses on a two-echelon model where the central depot does not hold any inventory. Extensions to more than two-echelon and stock-allowed central depot are also given at the end of the study. The control rule parameters are calculated by solving the problem through decomposition in two subproblems. In the first subproblem the expected system imbalance is minimized and the rationing fractions are determined. Then in the second subproblem the order-up-to levels are calculated such that the target fill rates are achieved. Numerical results of the computational example show that the presented control rule which is called Balanced Stock (BS) rationing is accurate, simple, flexible and more robust than the Consistent Appropriate Share (CAS) rationing policy.

van der Heijden, Diks and de Kok (1997) compare a number of practically applicable allocation rules in general N-echelon distribution systems where it is allowed to hold stock at all levels in the network. The goal is to achieve differentiated target customer service levels. The comparison is based on the difference between target fill rates and actual fill rates, where the actual fill rates are computed by discrete event simulation. They incorporate the allocation rules into algorithms that compute the order up to levels for arbitrary divergent N-echelon systems under periodic demand. They find out that the extension of BS rationing rule is the most accurate method. Given the imbalance is not too high, the extension of CAS rationing rule also performes well.

van der Heijden (1999) shows that the similar approach of the previously mentioned decomposition technique can be used to solve models including different shipment frequencies at the two levels of a two echelon distribution system. In this way inventory imbalance can be reduced compared to the immediate shipment made to the local warehouses upon receipt of goods by the central warehouse. A method is presented to determine the control parameters such that the target fill rates for the local warehouses are obtained. Extensive experimentation with the model shows that the stock reduction is relatively small for identical holding costs throughout the network. The largest reduction is obtained in case of frequent resupply in the downstream part of the network. When central holding costs are less than local holding costs, different shipment frequencies appear to be more useful.

The general research in multi-echelon inventory theory focuses largely on the interechelon flows of goods vertically between the echelons, with the common assumption that intraechelon shipments are not allowable. There are some other studies in the literature which allow additional coordination strategies such as transshipments between the end stock points, more than one shipment in a review period and redistribution of the inventory late in the review period. By the help of these variations mentioned above, a better customer service level is tried to be achieved with lower costs.

Jönsson and Silver (1987) make the estimation of customer service more tractable in that they consider a system involving only one complete redistribution late in the system order cycle. They study a two-echelon inventory system with stockless depot, n branch warehouses, normally distributed demand and allowable backorders. They evaluate the same system with and without a redistribution in the order cycle. The comparison of the two systems show that for the same service level the redistribution system gives a considerably smaller investment in inventory than does the system without redistribution. Since additional costs of transshipments of units between branch warehouses are incurred, a breakpoint for the shipment to holding cost ratio is obtained, in order to determine the conditions under which the redistribution system is economically viable. Also they have found that the redistribution system becomes more advantageous in situations with high demand variability, a long planning horizon, many branch warehouses, a high service level and short lead times.

Weng (1999) developes and analyzes a model for a two-echelon production and distribution system with random review intervals to study the value of different coordination strategies. Approximating end of cycle net inventory with a normal distribution, they develop analytical results for determining safety stock levels for each distribution center. It is shown that coordination among the manufacturing centre and n distribution centres can have a substantial impact on distribution center safety stocks for a given service level. The safety stock reduction due to coordination depends upon the number of distribution centres and the service level desired.

Tagaras (1999) studies the economics of risk pooling in multi-location inventory distribution systems, concentrating on three location groups using emergency lateral transshipment to respond to imminent shortages. A simple and fast heuristic algorithm is constructed, providing near optimal values of the base stock levels at the outlets. The heuristic solution can be used as a very good approximation of the optimal solution or as the starting point of an efficient search for the optimal base stock levels. By the help of a simulation study with a wide choice of model parameters, it is found that the benefits of risk pooling through transshipment are substantial and increase with the number of pooled locations; the type of transshipment policy in case of shortages does not affect significantly the system`s performance; forming balanced pooling groups consisting of locations that face similar demand is preferable.

Banerjee et al. (2003) examine the effects of two lateral shipment approaches in terms of some selected criteria in a two-echelon supply chain network through a series of simulation experiments under different operating conditions. The network consists of a single supply source at the higher echelon and multiple retail locations at the lower. It is found that either of the proposed lateral transshipment policies performes better than a policy of no-transshipment. Another intersting result is the superior performance of an ad-hoc policy to a more systematic transshipment technique.

The value of information in decision making in multi-echelon distribution systems is assessed by Güllü (1997), and Mitra and Chatterjee (2004). With the advent of technology, different stages of a multi-echelon system can exchange information through EDI in virtually no time. Therefore, the role of information in decision making in supply chains is getting more important.

Güllü (1997) analyzes a two-echelon allocation model under a forecast evolution model. Not only the correlation of demands through time and among retailers, but also the correlation of forecasts of demands are allowed. Under a general correlated demand-forecast structure, the approximate systemwide order-up-to level and the expected system cost are obtained. The results of the constructed model are compared with a system operating under standard demand model. The standard demand model results in higher order-up-to levels and higher system costs.

Mitra and Chatterjee (2004) examine the effect of utilizing demand information in a one warehouse two retailer system operating under periodic review. They show that dynamically setting the order-up-to level at the warehouse based on actual demand information at the retailers, always results in lower expected total costs than in the absence of demand information. They also specify that the order-up-to level at the warehouse is to be dynamic to use the benefits of availability of demand information.

All the studies mentioned so far consider the single item cases in multi-echelon inventory systems. Some of them suggest that, if there exist multiple items, the inventory control parameters are determined separately, however they say nothing about the replenishment process of these multiple items, since they do not include a transportation constraint in their studies. There are some studies about multi-item, multi-echelon networks for spare parts inventory which consider a serial inventory network and Poisson demand. Since the network in our system is divergent and the demand distribution of SKUs are not Poisson, these studies are not included in the literature study. There are some other studies that consider multiple items together with multi-echelon structure and try to integrate the inventory and transportation systems. But these studies are mainly for the network designs. Instead of determining the tactical and operational methods to operate a given network structure, they determine the number of echelons and the number of stock points in these echelons.

CHAPTER 4

INVENTORY-DISTRIBUTION SYSTEM DESIGN

In this chapter, the approach developed for the management of the inventory-distribution system for the proposed logistics network is discussed. Three modules of the approach are explained in detail.

The design for the management of the inventory-distribution system of the company consists of three modules. Two of these modules are at the tactical level and used once a year or a season whenever the demand pattern faced by the company changes. These tactical level modules are ‘Inventory Control Module’, which determines the control parameters of the inventory policy (order-up-to levels and rationing fractions) and ‘Truck Requirement Balancing and SKU Grouping Module’, which finds the minimum number of required trucks by balancing the number of truck usages of the system over the week, while grouping the SKUs and assigning the replenishment (review) days for each group. The third one called the ‘Shipment Consolidation and Truck Allocation Module’ is used on a daily basis and decides on the operational decisions such as the number of trucks sent to each regional warehouse, the SKUs which are rationed because of insufficient stock at the central warehouse, amount of SKUs sent to the regional warehouses, the backorders and surpluses due to truckload shipment, and the deviations from the inventory policy found in the first module. The third module tries to minimize the violation of the inventory policy, due to the transportation constraints that exist in the system. In this chapter we define the modules of the proposed system and at the end give the short summary of how the system is intended to work.

4.1 Inventory Control Module

The control of inventory in a distribution network has an objective of either optimization of total costs (inventory holding, ordering and replenishment costs), profit maximization or achieving a desired customer service level. When minimizing the costs, service measure is taken into consideration by having a penalty cost for the shortages, but service level consideration is not the primary objective. Generally, combining these two different objectives in a single model is very hard to achieve. Most of the studies in the literature on multi-echelon invetory systems take one of these objectives into account and leaves the other one as a performance evaluation tool.

Customer service level is very important for the FMCG industry, in which the analyzed company operates. The main objective is to achieve a desired service level and then retain this level with the lowest cost possible. The presence of many substitutable SKUs and brands in the market, lack of brand loyalty, high percentage of impulse buys and in-store brand selection make the availability of products on the shelves of sales points, the ultimate goal in this sector. The service level at the sales points can be at the desired level, if only the service level is high at every echelon throughout the supply chain. Therefore, service level for the distributors and chain markets at the regional warehouses is as much important as the service level to the end users (consumers). In the light of these facts, an inventory control model that is based on customer service considerations is preferred in this study.

Another important aspect of the inventory system design is stock rationing to be made in case of insufficient inventory at the central warehouse. There exist many different rationing rules developed in the literature. Their performances change depending on the environment where they are applied. Since the main objective of the inventory system in this study is determined to be the achievement of the target service level, the stock rationing rule to be chosen must be in accordance with this objective.

Van der Heijden (1997) study a multi-echelon, divergent inventory system for which the objective is to achieve differentiated target customer service levels and compare the performances of different stock allocation rules. He finds out that Balanced Stock Rationing rule is the most accurate method when the objective is the fill rate. This rationing policy has the objective of minimizing the approximate expected system imbalance. Minimization of the expected system imbalance results in the minimization of the deviation from the target fill rate. Thus, this allocation rule is chosen for the proposed system design, regarding its better performance than the other allocation rules in the literature.

The heuristic approach obtained by van der Heijden (1997) is easy to model and calculates the inventory control parameters very fast yielding accurate and robust results with respect to the other studies available in the literature. Therefore, the approach of van der Heijden (1997) is chosen for the case in this work. van der Heijden decomposes the problem into two. First, the allocation fractions are calculated such that an approximate expression for the expected amount of imbalance is minimized as much as possible. Next the order-up-to levels of regional warehouses and central warehouse are determined so as to guarantee the target fill rates. As stated in Van der Heijden (1997), van Donselaar proposes a simplifying adaptation which gives pretty good results for the heuristic obtained by van der Heijden; he uses this adaptation in the stock allocation fraction determination part. This adaptation can be found in van der Heijden (1997).

van der Heijden (1997) examines a multi-echelon environment which can be applied to a two-echelon case that have similar assumptions to the inventory system studied in this work. Assumptions of van der Heijden (1997) are as follows:

- Customer demand occurs only at the end stockpoints.
- The demand per period is stochastic and stationary in time.
- The demand is both independent across the end stockpoints and accross periods in time.
- All demand that cannot be satisfied directly from the stock on hand is backlogged.

- Partial delivery of customer orders is allowed.
- All lead times are constant.
- Lot sizing is not used, so any quantity can be ordered and delivered, and any allocation rule for material rationing for the end stockpoints is allowed.
- There is no capacity constraint on production, storage and transportation.

The main difference lies on the absence of transportation constraints. As mentioned before, in the inventory control part of the study, transportation constraints are relaxed. When the transportation constraints are taken into account, the results of the inventory control system may be affected. These constraints are considered later in the other two modules. Another difference from the assumptions of van der Heijden (1997) is the seasonality that exists in the demand for the SKUs of the company. This is overcome by forming stationary period groups in time and calculating different order-up-to-levels for these groups of periods. The order-up-to-levels are then time dependent. Therefore, the approach of van der Heijden (1997) enhanced by the adaptation offered by van Donselaar is applicable for the inventory control parameters setting part of our approach. In this module, the inventory control parameters for each SKU are calculated separately for each regional warehouse.

4.1.1 Basic Notation of the Inventory Control System

The notation used by van der Heijden (1997) approach converted to the two-echelon case is as follows:

N – number of regional warehouses

i – the index set of stockpoints $i = 0, \ldots, N$ where $i = 0$ is the index of the central warehouse

R – the length of the review period

L_0 – replenishment lead time for the central warehouse

L_i – replenisment lead time from the central warehouse to the regional warehouse i

D_i – demand per period at the regional warehouse i -a random variable with mean μ_i and standard deviation σ_i

$D_{i,\,Li}$ – demand at the regional warehouse i during its replenishment lead time L_i -a random varible with mean $\varepsilon_i = \mu_i L_i$ and standard deviation $\omega_i = \sigma_i \sqrt{L_i}$

$D_{i,\,Li+R}$ – demand at the regional warehouse i during its replenishment lead time L_i plus review period R -a random variable with mean $\nu_i = \mu_i(L_i+R)$ and standard deviation $\tau_i = \sigma_i \sqrt{(L_i + R)}$

D_{L0} – total demand at all regional warehouses during the replenishment lead time for the central warehouse L_0 -a random variable with mean $\nu_0 = L_0 \sum_{i=1}^{N} \mu_i$ and standard deviation $\tau_0 = (L_0 \sum_{i=1}^{N} \sigma_i^2)^{1/2}$

I_i – inventory position of the regional warehouse i just after rationing

β_i – target fill rate at the regional warehouse i

S_i – order-up-to level of the regional warehouse i

S_0 – order-up-to level of the central warehouse

$z_i[x]$ – the inventory position of the regional warehouse i just after allocation if the echelon inventory position of the central warehouse just before allocation equals x

p_i – allocation fraction from the central warehouse to the regional warehouse i

Δ - maximum physical stock at the central warehouse

x^+ - max{0,x}

4.1.2 Calculation of Order-Up-To Levels

First the expression for the fill rates, in terms of the control parameters S_0 and p_i is determined. At the beginning of period 0, central warehouse increases its echelon inventory position to S_0. Since the replenishment lead time is L_0 for the central warehouse, the order comes at the beginning of period L_0. So the echelon stock of the central warehouse just after the arrival of this order equals

$$S_0 - D_{L0}. \tag{4.1.1}$$

If this amount exceeds $\sum_{i=1}^{N} S_i$, the sum of the order-up-to levels of the regional warehouses, then every regional warehouse can raise its echelon inventory position to its order-up-to level. Thus,

$$D_{L0} \le \Delta \quad \Rightarrow \quad I_i = S_i \qquad \forall\ i \tag{4.1.2}$$

However, if $S_0 - D_{L0}$ is less than $\sum_{i=1}^{N} S_i$, then the on-hand stock of the central warehouse is rationed among the regional warehouses, according to the rationing fractions p_i.

According to the notation above, $z_i[x]$ is the amount allocated to the regional warehouse i, when available amount of the product to ration is equal to x at the central warehouse. Thus,

$$\Delta < D_{L0} \Rightarrow I_i = z_i[S_0 - D_{L0}] \qquad \forall\ i. \tag{4.1.3}$$

De Kok et al. (1994) and van der Heijden (1997) obtain a definition for the rationing function z_i. Both studies define the function in the same way, although the first one uses a Consistent Appropriate Share (CAS) rationing policy and the latter uses Balanced Stock (BS) rationing policy. The definition of z_i is as follows:

$$z_i[x] := S_i - p_i \left(\sum_{i=1}^{N} S_i - x \right) \qquad \forall\ i$$

$$x \leq \sum_{i=1}^{N} S_i \tag{4.1.4}$$

It is very clear that $\sum_{i=1}^{N} z_i[x] = x$, implying that $\sum_{i=1}^{N} p_i = 1$. From (4.1.2) to (4.1.4) it follows that

$$I_i = S_i - p_i (D_{L0} - \Delta)^+ \qquad \forall\ i \tag{4.1.5}$$

When the rationing fractions and the target service levels for the regional warehouses are known, calculation of the order-up-to levels S_i is a simple extension of the single location (R,S) model. Silver, Pyke and Peterson (1985) show that, if the following model is solved for S, the order-up-to level can be found:

$$E\,[(D_{L+R} - S)^+] - E[(D_L - S)^+] \ / \ R\mu = 1 - \beta \tag{4.1.6}$$

The above equation tells that the ratio of the difference between the expected shortages at the end and at the start of a replenishment cycle to the expected demand in a replenishment cycle gives $1 - \beta$.

In the two-echelon model, S is replaced by $S_i - p_i (D_{L0} - \Delta)^+$ and the remainder of the equation is the same as the one for the single echelon case. The order-up-to levels can be obtained by solving the following equation.

$$E [(D_{i, L+R} - (S_i - p_i (D_{L0} - \Delta)^+))^+] - E[(D_{i, L} - (S_i - p_i (D_{L0} - \Delta)^+))^+] / R\mu = 1 - \beta_i \tag{4.1.7}$$

Equation (4.1.7) can be solved for S_i numerically, if the stochastic terms in the numerator are approximated by a simple two-moment approximation. van der Heijden (1997) suggests to approximate these stochastic terms by Erlang mixtures with the first two moments. Erlang mixtures are the frequently used class of probability densities, when the parameters to be approximated are on the interval $[0,\infty)$. Another advantage of using Erlang mixtures approximation is that it can be used for approximating stochastic terms of any distribution. van Houtum and Zijm (1991) test this approximation procedure extensively and show that it performs well. A simple approximate expression is obtained by the help of Erlang Mixture approximation and this expression is solved for S_i using bisection.

Once all the order-up-to levels, S_i, are calculated, order-up-to level of the central warehouse S_0 can be obtained by the summation of the regional warehouse order-up-to levels and the maximum physical stock, Δ:

$$S_0 = \sum_{i=1}^{N} Si + \Delta \tag{4.1.8}$$

Holding central stock diminishes imbalance. Also in the case of our system, shipments made in full truckloads require to hold some central stock at the plant warehouses. As can be understood, the amount of central stock is a result of the choice of the parameter Δ, the maximum allowable stock. The amount of central stock equals $E[\Delta\text{-}D_{L0}]^+$, so it is convenient to express Δ in the mean system demand during the lead time L_0, say $\Delta = c\ E[D_{L0}]$ for some constant c. As the value of c increases, the amount of the central stock held increases. c=0 means no central stock.

It can be seen that given the target service levels and the rationing parameters, calculation of the order-up-to levels is not complex. The only requirement is the determination of the rationing parameters that add up to 1 and prevent the general balance assumption violation. General balance assumption state that the allocation rule which is described above yields nonnegative allocation quantities only. The right choice of the rationing parameters is given in the next section.

4.1.3 Determination of the Rationing Parameters

The allocation of central stock can cause imbalance in the system. Imbalance is the violation of general balance assumption and occurs when a negative quantity is allocated to one or more regional warehouses. Imbalance can be possible if the inventory position just before rationing exceeds the desired inventory position after rationing. This prevents other regional warehouses to get the amount deserved based on the allocation rule, although there exists excess inventories at one or more regional warehouses. Therefore, the main objective when defining the rationing parameters should be to minimize the system imbalance. Three different rationing rule is examined from the literature which are Fair Share Rationing, Consistent Appropriate Share Rationing and Balanced Stock Rationing. Balanced Stock rationing rule, proposed by van der Heijden (1997) minimizes the mean imbalance and performs the best among these allocation rules when the objective is the target fill rate attainment. Therefore, Balanced Stock rationing rule is chosen as the stocl allocation rule.

Amount of imbalance caused by a regional warehouse i at time t can be measured as

$$\Omega_i(t) := (\, - Q_i(t)\,)^+ \qquad (4.1.9)$$

where $Q_i(t)$ is the allocated amount to the regional warehouse i at time t. van der Heijden assumes that the regional warehouse i does not face any imbalance at the previous allocation in order to get a tractable expression for $\Omega_i(t)$. With this assumption, the following equation is obtained:

$$Q_i(t) = I_{i,t+R} – (I_{i,t} – D_{i,R}) \qquad (4.1.10)$$

While determining the allocation fractions, it is assumed that the central warehouse does not hold any stock. This assumtion is required since the allocation fractions are determined independently of the order-up-to levels. Under this assumption, by using normal approximation, van der Heijden (1997) shows that

$$E[\Omega_i] \approx \sigma_{\Omega i}\, f\,(\mu_{\Omega i} / \sigma_{\Omega i}) + \mu_{\Omega i}\, \Phi(\mu_{\Omega i} / \sigma_{\Omega i}), \qquad (4.1.11)$$

where $\mu_{\Omega i} = - R\mu_i$,

$\sigma^2_{\Omega i} = 2p_i^2 T \sum_{k=1}^{N} \sigma_k^2 + (R – 2p_i T)\, \sigma_i^2$,

$T := \min \{R, L_0\}$ and f (.), Φ(.) denote the standard normal density and distribution function, respectively.

The purpose is to obtain the allocation fractions (p_i) that minimize the mean imbalance at the central warehouse ($E[\sum_{i=1}^{N} \Omega_i]$). Since, p_i values only affect the $\sigma_{\Omega i}$ values, the effect of $\sigma_{\Omega i}$ on the mean imbalance of the central warehouse is considered. Differentiation of (4.1.11) to $\sigma_{\Omega i}$ proves that the mean imbalance is strictly increasing in $\sigma_{\Omega i}$, therefore $\sigma^2_{\Omega i}$ has to be minimized. If the allocation fractions minimizing the mean imbalance at the central warehouse are chosen, the following result is obtained:

$$p_i = \sigma_i^2 / (2 \sum_{k=1}^{N} \sigma_k^2) \qquad (4.1.12)$$

Unfortunately, the rationing parameters calculated as above do not add up to 1, but to 1/2. Therefore, another method is offered by van der Heijden (1997) to get the rationing fractions adding up to 1 and minimizing the mean imbalance as much as possible. In this method the following equation must hold for every regional warehouse.

$$\frac{dE(\Omega i)}{dpi} = f\,(\mu_{\Omega i} / \sigma_{\Omega i}) / \sigma_{\Omega i}\, T(2pi \sum_{k=1}^{N} \sigma_k^2 - \sigma_i^2) = c \qquad (4.1.13)$$

Using a bisection procedure, (4.1.13) is solved for p_i given some value of c. The value of the derivative, c, is determined by another bisection procedure such that the allocation fractions p_i add up to 1.

van Donselaar proposes a much simpler method to find the rationing parameters. Instead of minimizing the mean imbalance as much as possible, he chooses to minimize the sum of the variances of imbalance caused by the regional warehouses with respect to rationing parameters adding up to 1:

Minimize $\sum_{i=1}^{N} \sigma_i^2$ subject to $\sum_{i=1}^{N} p_i = 1$.

Using the Lagrange multiplier technique yields the following result:

$$p_i = \sigma_i^2 / (2 \sum_{k=1}^{N} \sigma_k^2) + (1 / 2N) \qquad (4.1.14)$$

This method simplifies the method proposed by van der Heijden and gives considerably good results.

4.1.4 Summary of the Approach for Inventory Control Parameters Setting

The heuristic approach that is used to calculate the inventory control parameters is summarized below. This approach has three steps and is repeated for all SKUs in the system.

(i) Compute the allocation fractions using the van Donselaar adaptation (4.1.14)

(ii) Determine for every regional warehouse i the order-up-to level S_i such that the fill rate at this warehouse i equals β_i. Calculate the S_i values by solving (4.1.7) using bisection after making the Erlang Mixture approximation.

(iii) Determine the order-up-to level of the central warehouse by (4.1.8).

This heuristic is coded in MATLAB 7.0. The MATLAB code gets the mean demand per period and standard deviation of demand per period, replenishment lead times, target fill rates for the regional warehouses, the review period, the replenisment lead time for the central warehouse and the maximum physical stock at the central warehouse as input and gives the order-up-to levels for the regional warehouses and central warehouse, and the rationing parameters for the regional warehouses as the outputs.

4.2 Truck Requirement Balancing and SKU Grouping Module

The inventory-distribution system under study has some transportation related constraints that distinguishes it from the studies in the literature about two or multi-echelon inventory systems. Transportation related constraints of the system are as follows:

- Truck capacities are limited.
- The number of trucks available is limited and the total number of trucks to be used in the system should be minimized.
- Trucks should go with full truckloads. This is because the transportation cost is incurred on the basis of distance travelled, regardless of the load amount and holding cost is identical for all warehouses, since the central warehouse and regional warehouses belong to the same company. Moreover, transportation cost is much higher than inventory holding cost in this industry. When the past years' cost figures are examined it is seen that yearly inventory holding cost is 40% of the yearly transportation costs.
- A truck can only go to one regional warehouse directly every period; there is no vehicle routing between the regional warehouses while sending the SKUs from plant warehouses to the regional warehouses, since routing increases the delivery time.
- Number of trucks that can be loaded from a plant during a day is limited.

- Utilization of trucks should be high because idle trucks create extra cost on the system.
- SKUs are stored on pallets at the regional warehouses. SKUs can be damaged when handled in parcels. Therefore, shipment unit to the regional warehouses is the pallet, loading and unloading palletized products takes much less time than the products in parcels.

These transportation constraints in the multi-item environment with almost 200 SKUs, make the truck utilization, allocation and order consolidation problem very complicated. As a result of these complicating constraints, deviations from the inventory control policies occur, since sometimes more or less than the amount required is sent to the regional warehouses. However, the important point here is to use the trucks with high utilization, while holding the deviations from the desired inventory levels calculated in the inventory control parameters setting module as small as possible, under the constraints placed by the transportation system.

Operating the system with the minimum number of trucks possible and high utilization rates can only be possible if the trucks travel continuously throughout the week and if the shipment schedules are dispersed evenly during the weekdays, that is, the number of trucks loaded each day should be close to each other over the week. Trucks in the fleet of the firm must either be carrying SKUs to the regional warehouses or returning back. This can be achieved by coordinating the review periods. SKUs are divided into groups having the same replenishment day (review time), holding the truck usage differences among the days of the week at minimum.

All of the replenishments and reviews are made weekly at the firm. Therefore, the review period R in the inventory system is also taken as a week for all the SKUs. Although the review period of all the SKUs is the same, the review times can be different. For example, two different SKUs can have a review period of 6 days (a week has 6 workdays), but one of them may be reviewed every Monday while the other may be reviewed every Friday. In accordance with this, the shipment days and truck requirements of these two SKUs may be on different days. So, adjusting the review days by placing the SKUs into 6 different groups, while making the truck requirements of the regional warehouses balanced among the days of the week, can result in the coordination required for high truck utilization and minimum number of trucks requirement.

An integer programming model for grouping the SKUs and assigning them a review day is constructed and coded in GAMS. The model balances the truck requirements among the days of the week, according to the mean demand of the SKUs at the regional warehouses. Note that review days are SKU specific. Review day of an SKU at the different regional warehouses is the same in order to make the control of echelon inventory policy possible. The IP model is as follows:

Indices:

i – regional warehouse index $\quad i = 1,...,6$

j – SKU index

k – plant index $\quad k = 1,...,4$

t – shipment day index $\quad t = 1,...,6$

Parameters:

m – number of SKUs

C – truck capacity

d_{ij} – mean demand for SKU j at the regional warehouse i

TLC_k – truck loading capacity of plant k in a day

$$y_{kj} - \begin{cases} 1 & \text{if SKU } j \text{ is produced at plant } k \\ 0 & \text{Otherwise} \end{cases}$$

Decision variables:

V_{ikt} – number of trucks sent from plant k to the regional warehouse i on day t

RT_{it} – number of trucks received by the regional warehouse i on day t

WT_i – minimum number of trucks required for regional warehouse i

$$r_{jt} - \begin{cases} 1 & \text{if SKU j is replenished on day t} \\ 0 & \text{otherwise} \end{cases}$$

TT – total number of trucks required

$$\text{Minimize TT} \qquad (4.2.1)$$

Subject to

$$\sum_{j=1}^{m} d_{ij}\, y_{kj}\, r_{jt} \leq C\ V_{ikt} \qquad \forall\ i, k, t \qquad (4.2.2)$$

$$\sum_{t=1}^{6} r_{jt} = 1 \qquad \forall\ j \qquad (4.2.3)$$

$$\sum_{i=1}^{6} V_{ikt} \leq TLC_k \qquad \forall\ k, t \qquad (4.2.4)$$

$$\sum_{k=1}^{4} V_{ikt} = RT_{it} \qquad \forall\ i, t \qquad (4.2.5)$$

$$WT_i \geq RT_{it} \qquad \forall\ i, t \qquad (4.2.6)$$

$$TT = \sum_{i=1}^{6} WT_i \qquad (4.2.7)$$

$$V_{ikt} \geq 0 \qquad \forall\ i, k, t \qquad (4.2.8)$$

$$RT_{it} \geq 0 \qquad \forall\ i, t \qquad (4.2.9)$$

$$WT_i \geq 0 \qquad \forall\ i \qquad (4.2.10)$$

$$TT \geq 0 \qquad (4.2.11)$$

$$m_{jt} = 0 \text{ or } 1 \qquad \forall\ j, t \qquad (4.2.12)$$

(4.2.2) assures that total amount of shipment made from plant k on day t to regional warehouse i must be less than or equal to the total capacity of the trucks sent from plant k to the regional warehouse i on day t.

By constraint (4.2.3), SKU j can have only one replenishment day. Constraints (4.2.2) and (4.2.3) together also guarantee the fullfilment of all demand while assigning the replenishment day of SKU j.

(4.2.4) limits the number of trucks sent from plant k to all regional warehouses by the maximum possible amount that can be loaded at that plant.

(4.2.5) determines the number of trucks sent to regional warehouse i on day t.

(4.2.6) determines the maximum number of trucks received in a day by the regional warehouse i during the week. This is also the required number of trucks to be used for the regional warehouse i, since it is the maximum usage for that warehouse during the week. The maximum gives the lower bound for the number of trucks required in a day.

(4.2.7) finds the total number of truck requirements for all regional warehouses. This equation determines the daily fleet size of the company.

(4.2.8) to (4.2.11) are the nonnegativity constraints for the decision variables.

(4.2.12) states that SKU j is either replenished on day t or not.

The objective function (4.2.1) minimizes the total number of trucks required and at the same time the maximum number of trucks used for a regional warehouse in a day. Since the total amount of demand to be met does not change throughout the week and the shipment of whole demand is guaranteed, only way to minimize the daily truck requirements for the regional warehouses is to allocate SKUs to the replenishment days accordingly. Therefore, the objective function balances the truck usages between the days of the week for each regional warehouse by balancing the daily requirements through replenishment (review) day assignment. By the help of this model, total daily amount of shipments to the regional warehouses is allocated to the replenishment days almost equally.

4.3 Shipment Consolidation and Truck Allocation Module

Inventory control parameters setting and review day determination for SKU groups by balancing the number of truck requirements during the weekdays are tactical problems that is to be solved once a year or a season. However, inventory replenishment and truck allocation is an operational problem and performed everyday. Because of the transportation constraints, this activity affects the amount of SKUs sent to the regional warehouses. The group of SKUs which are reviewed the same day are replenished together. The replenishment and review periods are synchronized since both the review period length and the leadtime to the central warehouse is a week. Each day inventories at the regional warehouses and the central warehouse of the group of SKUs to be replenished on that day are reviewed (these groups are determined by the model that is described in the previous section). The amounts that raise the echelon inventory position of the central warehouse of each SKU to its order-up-to level are placed as orders of the central warehouse to the plants. Also at the same time the previous orders placed by the central warehouse to the plants for these groups of SKUs arrive at the central warehouse (both the lead time to the central warehouse and the review period is a week - replenishment period and review period synchronization). Then this physical stock at the central warehouse is allocated to the regional warehouses according to the amounts that are required to increase the inventory positions at the regional warehouses to the order-up-to level. In case of insufficient inventory the available inventory is rationed by the rationing fractions. However, this does not end the replenishment process. Due to the transportation constraints in the system, the replenishment of the inventories can not be performed exactly as the requirement of the inventory policy. As a result of the constraints mentioned before, some of the SKUs are sent less and some are sent more than the requirements of the regional warehouses. This affects the performance of the inventory policy determined with no transportation constraints.

The success of inventory replenisment and truck allocation process lies on the degree of violation of the requirements of the inventory policy under the transportation constraints. This process should allocate the trucks to the regional warehouses and assign the amount of SKUs to be shipped to each regional warehouse by those trucks, such that the violation of the inventory policies is minimized. Inventory replenishment and truck allocation process give the following decisions:

- Number of trucks sent to each regional warehouse
- The amount and type of SKUs sent to each regional warehouse
- The positive (surplus) and negative (backlog) deviations from the requirements of the regional warehouses of each SKU
- The SKU types that are rationed among the regional warehouses due to insufficient inventory at the central warehouse

A Mixed Integer Programming model is constructed and coded in GAMS for the inventory replenishment and truck allocation process. This model minimizes the maximum deviation from the inventory policy of [SKU–regional warehouse] pairs, while satisfying the transportation constraints. The model tries to allocate the transportation constraints fairly to the [SKU-regional warehouse] pairs. During this allocation the importance of the regional warehouses is considered. The importance factor of a regional warehouse where the occasion of a stockout is much more undesirable is higher.

Indices:

i – regional warehouse index $i = 1,...,6$

j – SKU index

k – plant index $k = 1,...,4$

Parameters:

m – number of SKUs

C – truck capacity

S_{ij} – order-up-to level of SKU j at the regional warehouse i in pallets

I_{ij} – inventory position of SKU j at the regional warehouse i in pallets

I_{0j} – inventory position of SKU j at the central warehouse in pallets

OS_{0j} – on hand stock of SKU j at the central warehouse in pallets

p_{ij} – rationing fraction of of SKU j for the regional warehouse i from the central warehouse

A_i – importance factor of the regional warehouse i

AT – number of trucks available for shipment on that day

Decision variables:

X_{ij} – amount of SKU j sent to the regional warehouse i

B_{ij} – backordered amount of SKU j for the order of the regional warehouse i

E_{ij} – amount of SKU j that is sent in excess of the order of the regional warehouse i

T_i – number of trucks sent to the regional warehouse i

$$F_j - \begin{cases} 1 & \text{if SKU j is not rationed due to insufficient inventory} \\ 0 & \text{Otherwise} \end{cases}$$

MD – maximum deviation from the optimal inventory policy with respect to S_i

Minimize MD (4.3.1)

Subject to

$$X_{ij} + B_{ij} - E_{ij} = S_{ij} - I_{ij} \qquad \forall\ i, j \qquad (4.3.2)$$

$$\sum_{j=1}^{m} X_{ij} = C\ T_i \qquad \forall\ i \qquad (4.3.3)$$

$$\sum_{i=1}^{6} X_{ij} \leq OS_{0j} \qquad \forall\ j \qquad (4.3.4)$$

$$X_{ij} - p_{ij}\ I_{0j} \leq M\ F_j \qquad \forall\ i, j \qquad (4.3.5)$$

$$\sum_{i=1}^{6} (S_{ij} - I_{ij}) - I_{0j} \leq M\ (1 - F_j) \qquad \forall\ j \qquad (4.3.6)$$

$$\sum_{i=1}^{6} T_i \leq AT \qquad (4.3.7)$$

$$MD \geq (A_i B_{ij} + (1 - A_i) E_{ij}) / S_{ij} \qquad \forall\ i, j \qquad (4.3.8)$$

$$X_{ij}, B_{ij}, E_{ij} \quad \text{positive integer} \qquad \forall\ i, j \qquad (4.3.9)$$

$$T_i \quad \text{positive integer} \qquad \forall\ i \qquad (4.3.10)$$

$$Fj = 0 \text{ or } 1 \qquad \forall\ j \qquad (4.3.11)$$

$$MD \geq 0 \qquad (4.3.12)$$

$$M >> 0 \qquad (4.3.13)$$

(4.3.2) determines the amount of SKU j required by the regional warehouse i, taking the difference between the order-up-to level and inventory position. This amount is determined with no transportation constraint and sufficient inventory availability assumption. (4.3.2) is also the balance equation between the ordered amount of SKU j by regional warehouse i and amount of SKU j sent to regional warehouse i. The differences between these two is either the backordered amount or the amount sent in excess of the requirement.

(4.3.3) limits the amount sent to the regional warehouse i by the capacity of all the trucks sent to that regional warehouse. Furthermore, as this constraint is set as an equality constraint, it obtains full truckload shipments.

(4.3.4) ensures that the total amount of SKU j sent to all of the regional warehouses cannot be more than the available central stock.

(4.3.5) and (4.3.6) together determine if SKU j is to be rationed among the regional warehouses due to insufficient stock at the central warehouse or not. If a rationing is required, the amount of SKU j sent to the regional warehouse i cannot be more than the amount allocated by the rationing fraction.

Usage of more than the available number of trucks is not allowed by (4.3.7).

(4.3.8) finds the maximum degree of deviation from the inventory policy weighted by the importance factor of the regional warehouses, in proportion to the order-up-to level. Deviation from the inventory policy can be in two ways, either some of the requirement is backlogged or excess amount is sent. The degree of deviation is also related with the order-up-to level together with the excess or backlog amount. The same amount of excess or backlog order causes more violation of the inventory control policy for the [SKU-regional warehouse] pair with less order-up-to level. Therefore, the degree of deviation is calculated as the ratio of the amount of deviation to the order-up-to level. Importance factors for the regional warehouses are used as weighting factors, because the impact of inventory policy violation is different for different regions. Some regions have more strategic importance for the company to retain their market position. Also these regions are affected by shortage and overage in the opposite way. In a region, that is given a high importance weight, backlog is not welcome, whereas sending excess amount is more natural. Therefore, the importance factor weights are A_i for backlog and $(1 – A_i)$ for excess amount.

Constraints (4.3.9) – (4.3.13) say that all of the decision variables except for the one which determines the requirement for rationing are positive integers. The rationing requirement parameter F_j is either 0 or 1. Also M is a big positive number.

The objective function (4.3.1) tries to minimize the maximum degree of weighted deviation from the inventory policy found by the constraint (4.3.9). The objective function fairly allocates the effect of transportation constraints on inventory policies to all of the [SKU-regional warehouse] pairs. The objective function minimizes the deviations from the inventory parameters calculated at the inventory control module.

4.4 Summary of The Inventory-Distribution System Design

1. Inventory control parameters (order-up-to levels) are determined at the beginning of each month by the Inventory Control Module. These parameters are not changed until the next run of the module.

2. SKUs are grouped and replenishment (review) schedules of these groups are determined by the Truck Requirement Balancing and SKU Grouping Module, whenever the demand patterns of SKUs change.

3. Every day, in the morning the echelon inventories at the central warehouse and at the regional warehouses of the SKUs that are to be reviewed that day are checked. Orders are placed to the plants, in order to bring the echelon inventory positions of these SKUs at the central warehouse to their order-up-to levels. Then the outstanding orders of the central warehouse for the SKUs arrive at the central warehouse. Physical inventory positions of the SKUs at the central warehouse are updated. The inventory positions at the regional warehouses are sent to the Shipment Consolidation and Truck Allocation Module. This module gets also the order-up-to levels of these SKUs at each regional warehouse and the physical available inventories at the central warehouse. The optimization model is run and the amount of each SKU to be sent to each warehouse and the allocation of the trucks to the regional warehouses are determined under the stock availability and transportation constraints. Finally, according to the results of this module, the replenishments of the inventories at the regional warehouses are made within the replenishment lead times.

Inputs, outputs and the relationships of the three modules that constitute the inventory-distribution system can be seen in Figure 4.1.

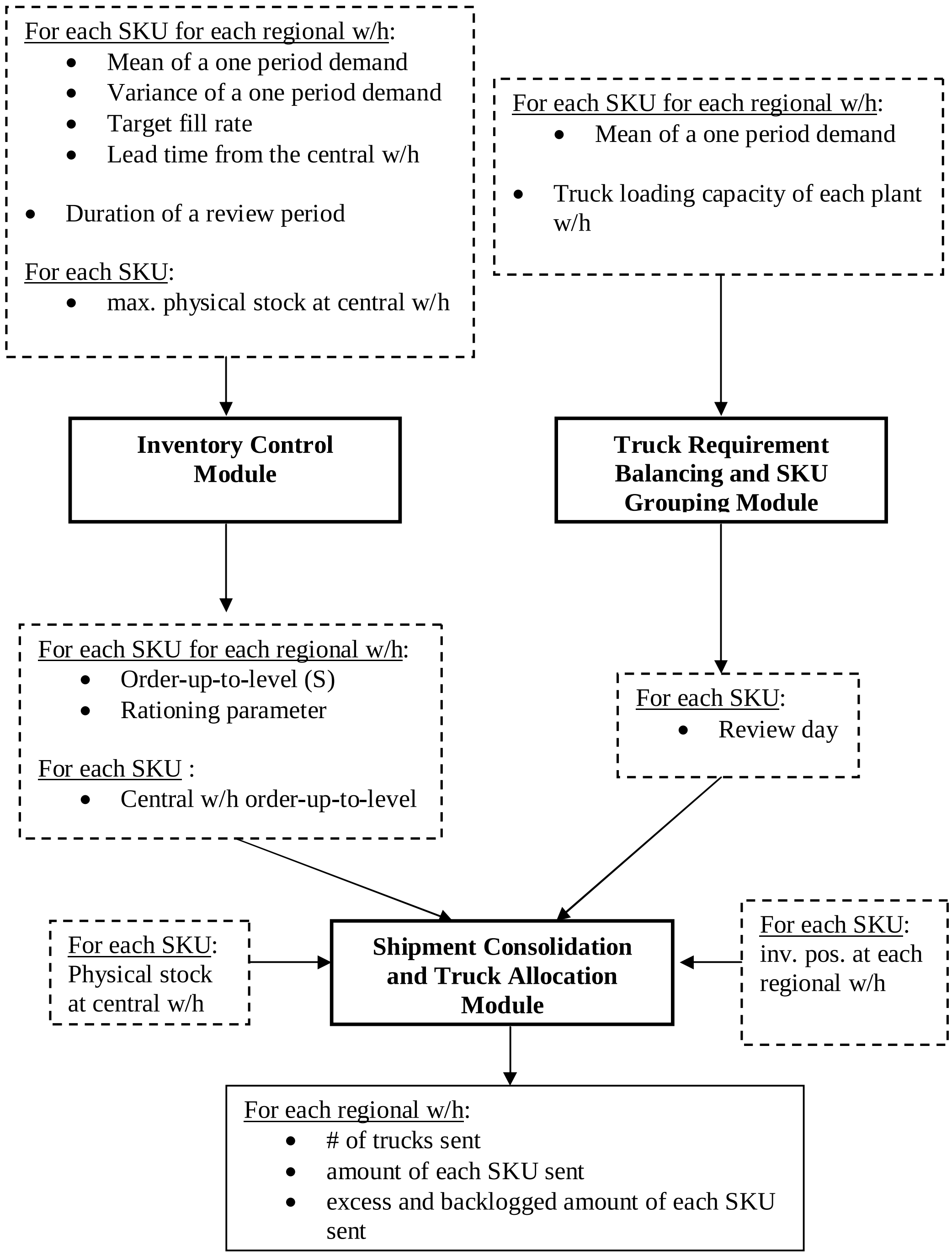

Figure 4.1 Inputs, outputs and relationships of three modules

CHAPTER 5

EVALUATION OF THE PROPOSED SYSTEM

In this chapter, experimentation with the proposed inventory-distribution system developed is explained. In order to evaluate and investigate the performance of the proposed system, it is simulated with retrospective data.

In this study, the main focus is to improve the inventory-distribution system of the company and verify the benefits of changing the single-echelon structure of the network to a two echelon structure along with a new inventory-distribution management system. Comparison of the performances of the current and the proposed system is very essential in this work. Therefore, instead of using generated data or constructing some alternative scenarios, retrospective data is used to simulate the approach developed in the previous chapter. By this way, the existing system and the proposed system can be compared in terms of performance measures of the inventory-distribution system.

5.1 The Performance Measures

The main issue in any inventory-distribution system is the trade-off between the total cost of the system and the service level for the end customers. Total cost for such a system is basically composed of inventory holding cost, transportation cost and warehouse operating cost. Service level can be measured in terms of the fill rate to the customer orders and the response time when delivering the orders of a customer. Fill rate is defined as the percentage of demand that is directly satisfied from the shelf. Response time is the time that elapses between the placement of an order by the customer and delivery of that order to the customer warehouse. Response time is also a function of the travelling distance between the supplier and the buyer, if the customer's requirements are available at the warehouse.

There are also some performance measures specific to the problem analyzed in this study. The utilization of the transportation vehicles, the effect of transportation related constraints on the inventory replenishments and the deviation of the production orders from the customer orders, which results in wrong mixture and amount of goods in the inventory, are the performance measures specific to the problem environment in this study.

The performance measures to be evaluated in this work can be summarized as follows:

- Deviation of the actual fill rate from the target fill rate,
- average amount of inventory held in the system; comparison of the inventory levels of the existing system and the proposed system for the same fill rate,
- transportation cost; existing system vs. proposed system,
- response time; distances between the customers and the warehouses of the company in the existing system vs. proposed system,
- utilization of trucks,
- deviation from the inventory replenishment requirements,
- deviation between the production orders and customer orders.

5.2 The Data and Parameters

As mentioned before, experimentation is made by the retrospective data. Distributors' and chain markets' daily orders placed between the beginning of year 2002 and ninth month of the year 2005 for each SKU are used as the demand data for the evaluation of the proposed system. These customer orders are in units of parcels. Then this demand data is consolidated according to the customer–regional warehouse assignments made in Bulur and Çölova (2004), that is, the orders of distributors and chain markets which are served by the same regional warehouse are summed to get the daily demand at each regional warehouse.

SKUs are stored on pallets at the plant and regional warehouses and palletized shipments are made from the plant warehouses to the regional warehouses. The unit used in the inventory replenishments is pallet. Therefore, the matrix showing the number of parcels on a pallet for each SKU is obtained. However, the shipments from regional warehouses to the customers are made in units of parcels, as the demand of the customers are in parcels. When shipment is made in parcels, the volume occupied by the parcels in the truck is important, rather than the number of parcels. For this reason, the volume of a parcel of each SKU is also obtained.

High-capacity trucks are used in inbound transportation (between plant warehouses and regional warehouses) each of which has a loading capacity of 48 pallets and regular trucks are used for outbound transportation (shipment from regional warehouses to customers) each of which has a net capacity of 36 m^3. Trucks are paid based on the distance travelled. High-capacity trucks are paid 1.10 YTL/km and regular trucks are paid 0.80 YTL/km.

For the comparison of the average inventory held in the existing and proposed system, the amount of inventory should be expressed in tons. Thus, a matrix is formed, showing the weight of a parcel of each SKU.

5.3 Seasonality of the Demand Data

Inventory Control Parameters Setting Module uses the heuristic approach offered by van der Heijden (1997). One of the assumptions of this approach is the stationarity of the demand in time. However, as mentioned in the previous chapter, there exists seasonality in the demand for the SKUs in this study.

Seasonality in the demand data can be handled by dividing the months of a year into groups that have similar demand characteristics. These groups themselves have a stationary demand, and based on this data, different inventory control parameters are calculated for each group. That is, instead of having a single constant order-up-to-level along a year, there will be as many different order-up-to-levels as the number of the groups formed by the months that show the same demand characteristics. The inventory control parameters will be the same for the months in the same group.

In the company, seasonality constants are calculated for each SKU by the regression analysis using the 36 past monthly data. If the demand is the same for an SKU in every month of a year, the seasonality constant for each month is 1. If demand differs between the months, the constants for each month is different and all of the constants add up to 12 (as there are 12 months in a year). Seasonality constants are not the same for all SKUs, but have the same seasonality pattern. Therefore, average seasonality constants are used in the study.

When the averages of seasonality constants of all SKUs are taken, the following graph shown in Figure 5.1 is obtained.

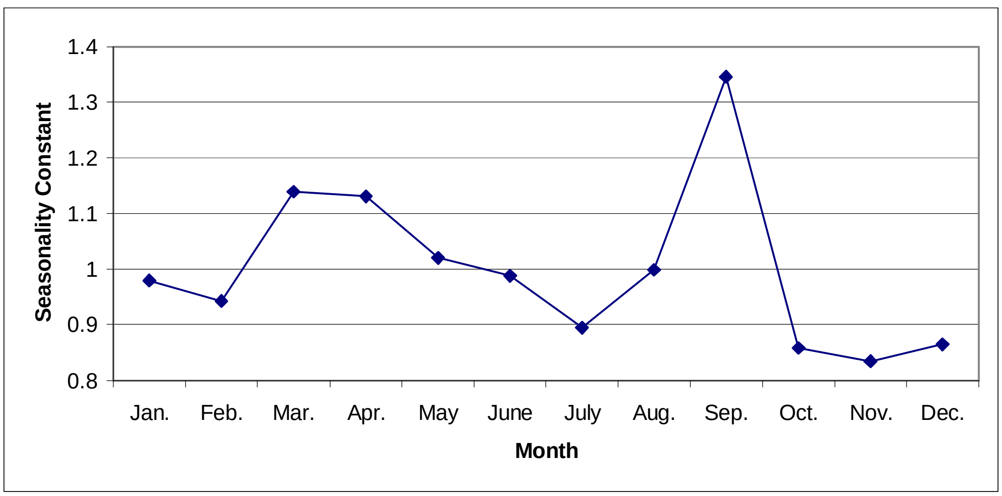

Figure 5.1 Averages of Seasonality Constants

When Figure 5.1 is examined, three groups of months are formed. Group 1 has seasonality constants greater than 1.1 and includes the months March, April and September. Group 2 has seasonality constants between 0.9 and 1.1 and consists of the months January, February, May, June and August. The months, July, October, November and December belong to Group 3 with seasonality constants less than 0.9. During the experimentation of the proposed system, these groups are used and different inventory control parameters are calculated for each group o months using the demand data for the months belonging to the same group as the input for the Inventory Control Parameters Setting Module.

5.4 Experimentation of the Proposed System without the Transportation Constraints

The regional warehouse demand data is divided into three groups, according to the month when the demad occurred, in parallel with the groups found in the previous section. Averages and standard deviations of the demand data of each group are found for each SKU. These are used as inputs for the Inventory Control Parameters Setting Module coded in MATLAB 7.0.

Review period is taken as a week (R=7 days). The lead time for the replenishment of the central warehouse inventory is set as a week (L_0=7 days), whereas the lead time for all regional warehouses from the central warehouse is one day (L_i=1 day). Lead times and review period length are the same for all SKUs. The constant which determines the amount of central stock is set to 0.2 (c=0.2) for all SKUs.

The fill rate in the existing system is 90% on the average for the last twelve months. In order to make comparisons with the existing system, inventory control parameters are calculated for a target fill rate of 90% by the help of the MATLAB code. Three different order-up-to-levels and stock allocation fractions are found for each SKU to be used in different months. These order-up-to-levels are in units of parcels.

In order to observe the performance of the Inventory Control Parameters Setting Module, the system is simulated for the time period from the beginning of 2003 until the ninth month of 2005, without any transportation constraint. By excluding the transportation constraints, we have the chance to compare the results of the heuristic in this system, with the results obtained by van der Heijden (1997). The simulation of the system without any constraints is performed as follows:

The system is started with all the regional warehouse inventory positions for each SKU equal to the order-up-to-levels determined for the month January. The central warehouse physical stock for each SKU is set to the maximum available level for that SKU. This is done for the initialization of the system. The system is started with the ideal level.

For each SKU:

- At the beginning of each week (R=7), the date is checked and the inventory control parameters are set according to the group that month belongs to. The echelon inventory position of the central warehouse is checked. The central warehouse gives an order to raise its echelon inventory position to its order up to level S_{0j}. This order comes at the beginning of next week.

- At the same time, the outstanding order of the central warehouse, issued one week before arrives at the central warehouse (L_0=7). Net inventory (physical stock) of the central warehouse, I_{0j} is updated. Then the physical stock at the central warehouse is allocated to the regional warehouses. Each regional warehouse's inventory position, I_{ij} is checked. The shortfall, S_{ij}-I_{ij}, of each regional warehouse from its order-up-to-level, S_{ij}, is determined. Next, the net inventory at the central warehouse, I_{0j}, is checked to see if it is sufficient to increase all of the regional warehouses' inventory position, I_{ij}, up to the desired position, S_{ij}. If it is possible to do so, the shortfall amounts are shipped to the regional warehouses and inventory position of each regional warehouse is set to its order-up-to-level, $I_{ij} = S_{ij}$. On the other hand, if the central warehouse runs out of stock, the available net inventory is rationed among the regional warehouses and shipment amounts determined accordingly raise the inventory positions of the regional warehouses as much as possible, $I_{ij} \leftarrow I_{ij} + p_{ij} * S_{0j}$. p_{ij} is the rationing fraction of SKU j, from central warehouse to regional warehouse i. Since the lead time from central warehouse to regional warehouses is one day, $L_i=1$, the next day net inventory of the regional warehouse is updated. If there exists any imbalance no shipment is made to the regional warehouse where the requirement is negative.

- At the end of each day, demand occurs at each regional warehouse. Net inventory of the regional warehouses are updated. The fill rate for that day is calculated. If the net inventory becomes negative this means that, the negative amount is backlogged for the following day.

- At the end of each week average fill rate for the regional warehouse is calculated and recorded.

- The net inventories of the regional warehouses and the central warehouse are checked and recorded after the allocation of central stock to the regional warehouses at each replenishment period. Average inventory in the system is the total amount of inventory at all the warehouses just after the allocation.

- At the end of this retrospective simulation, actual vs. target fill rate comparisons and average inventory held is calculated. To obtain the average inventory held, net inventories at both the regional warehouses and at the central warehouse are multiplied by the weight of a parcel.

The retrospective simulation of the system started with the initial condition that all the warehouses have inventory positions equal to their order-up-to-levels. When no transportation constraints exist and target fill rate equals 90% for all SKUs and regional warehouses, the simulation resulted with an average inventory of 3805 tons. The value of the average inventory obtained by the proposed system is 18,700,000 YTL. This value is obtained by multiplying the amount of inventory of each SKU by its cost. The average of the mean actual fill rates obtained by simulation for 217 SKUs is 89.45%. This actual fill rate is slightly less than the target fill rate. On the average, the deviation of the average fill rates of 217 SKUs from the target fill rate is -0.61%. The maximum deviation observed is 4.87%.

Although the average actual fill rate does not deviate too much from the target fill rate, deviations of the actual fill rates from the target fill rate vary in time. The histogram for the deviation of the actual fill rate from the target fill rate for a group of SKUs is shown in Figure 5.2, to give an idea about the robustness of the system in terms of actual fill rate. As can be seen, despite the good result for the average actual fill rate, the robustness of the fill rate is not as expected. This high variation, in spite of a good average result may be the consequence of the incentive system which causes the orders to be higher in the last weeks of the month. The distribution of the demand in a month, causes higher inventories than needed during the first weeks of the months and lower inventories than needed during the last weeks of the months. The former results in high fill rate and the latter results in low fill rate. If the orders of the customers are distributed evenly throughout the month, the robustness of the system in terms of fill rate may be better and the avereage inventory held may be less as the variations of the demand in time decrease. Another reason for the variation of actual fill rate, may be the high demand observed in September. Although groups are formed according to the seasonality constants, demand which occurs in September is still more than the demand occuring in other two months in the same group.

The average inventory in the existing system is 4200 tons per week for the last twelve months and the average fill rate is 90%. The value of the average inventory in the existing system is 20,700,000 YTL. When compared to the existing system, the proposed system resulted with almost the same level of fill rate, 89.5%, with average inventory of 3805 tons, which is 9.4% less than the average inventory held in the existing system. Also the value of the average inventory in the proposed system is 2,000,000 YTL less than the value of the average inventory in the existing system. Average inventory decreases, despite the fact that holding stocks at a two-echelon network with more stockpoints, increases the inventory in the system.

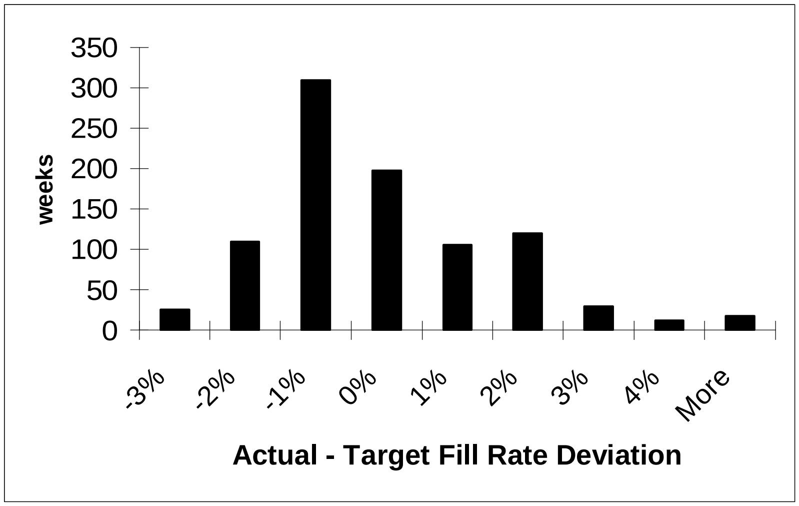

Figure 5.2 Histogram of Actual – Target Fill Rate Deviation for 90% Target Fill Rate without Transportation Constraints

Having seen that the proposed system works with less inventory than the existing one for the same target fill rate, the simulation is repeated for a target fill rate of 95%. At the same period, when target fill rate is 95%, the average inventory held is 4012 tons. The average of the mean actual fill rates for the 217 SKUs is 94.61%. On the average, the deviation of the actual fill rate of 217 SKUs from the target fill rate is observed as -0.41%. The maximum absolute deviation observed is 4.16%. The histogram of actual minus target fill rate deviation for a group of SKU when target fill rate is 95% is shown as an example in Figure 5.3.

As can be seen the proposed inventory-distribution system gives better results in terms of actual minus target fill rate deviation, when the target fill rate is higher. The robustness of the system in terms of the fill rate is still not as it is expected to be. However, the deviations are much more concentrated between -1% and 1%, which is better than the case for 90% target fill rate. Van der Heijden (1997) states that, all rationing policies perform better for high service levels than for low service levels. This claim coincides with the results obtained in our system.

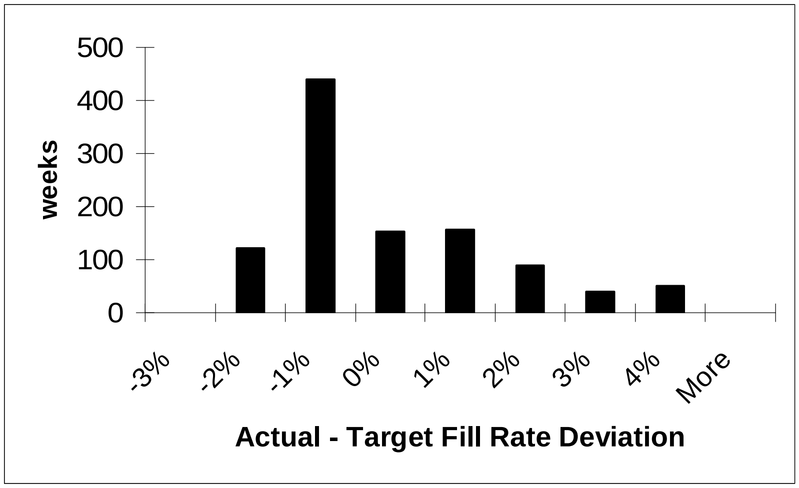

Figure 5.3 Histogram of Actual – Target Fill Rate Deviation for 95% Target Fill Rate without Transportation Constraints

When the results of the experiment for the proposed system with the target fill rate of 95% is compared with the existing system, it can be seen that, by holding almost the same level of inventory (proposed: 4212 tons (20,825,000 YTL), existing: 4200 tons (20,700,000 YTL)), the fill rate can be increased on the average from 90% to 94.61%. This shows that, by changing the structure of the system from a forecast driven push system to a demand driven pull system, right composition of products are held in the inventory.

The comparison of the existing system with the proposed system for 90% and 95% target fill rates when no transportation constraints exist can be seen in Table 5.1.

As mentioned before, in the existing system the production orders placed by the marketing department as the forecast of the amounts to be shipped to the customers in a specific week, match with a percentage of 70% with the orders that come from the customers of the company. The 30% deviation results in holding the inventory of the wrong mix of SKUs. This deviation diminishes in the proposed system, since the same fill rate is obtained with less inventory and higher fill rate can be achieved with the same level of inventory.

Table 5.1 Comparison of Existing System with Proposed System without Transportation Constraints

	Avg. Inventory (tons)	Target Fill Rate	Avg. Actual Fill Rate
Existing System	4200		90%
Proposed system with 90% target fill rate	3805	90%	89.5%
Proposed system with 95% target fill rate	4212	95%	94.6%

5.5 Experimentation of the Proposed System with Transportation Constraints

The proposed system gives satisfactory results when the transportation constraints are relaxed in the experimentation. However, this system will be used in an environment where some constraints exist, that will affect the outcomes of the inventory policy. Thus, the proposed system is evaluated with same data and for the same period, considering the transportation constraints. The aim is to see the effects of the constraints on the performance measures of the system. The inventory-distribution system approach, consisting of the three modules is used in this evaluation.

The first module of the approach, Inventory Control Parameters Setting Module, does not differ whether the transportation constraints are included in the system or not. Therefore, in this second experimentation the same order-up-to-levels and rationing fractions found in the previous section for the no transportation constraints case are used.

In the previous experimentation, the replenishment periods are the same for all SKUs. The inventory positions of all SKUs are reviewed and replenished at the same time. However, the transportation constraints in the system requires the replenishments to be evenly distributed in time as much as possible. For this purpose, the Truck Requirement Balancing and SKU Grouping Module is developed. The module is explained in detail in the previous chapter. It tries to equate the daily truck requirements over the week.

Since shipments are made in six days of a week (except Sunday), the SKUs are placed into six groups, for which the same review and replenishment days are assigned. The review day of the SKUs in the same group coincides with the arrival of the previously placed orders for that SKUs to the central warehouse, as both the review period and the lead time to the central warehouse is a week. For example, 30 of the SKUs are placed in the same group as a result of the Truck Requirement Balancing and SKU Grouping Module and the inventories of these SKUs are reviewed on Mondays. Each Monday orders are placed according to the requirements of the echelon order-up-to-level of the central warehouse. These orders arrive at the central warehouse the next Monday, during the next reviewal of the inventories of the same SKUs. Then the physical inventory at the central warehouse is allocated to the regional warehouses according to their order-up-to-levels and limitations of the transportation constraints. The allocated amounts are loaded on the trucks and regional warehouses receive these amounts on Tuesday.

The model developed for the Truck Requirement Balancing and SKU Grouping Module is run and the SKUs are placed into six different groups. Since the review period is a week, average weekly demands of the regional warehouses in a year for each SKU in units of pallets is used as an input for the model. One of the regional warehouses is located at the same place where the plants of the companies are located. Therefore, that regional warehouse is excluded from this model, as no shipment is required for it. The results of the IP model can be seen in Table 5.2.

As can be seen in Table 5.2, the number of trucks required by a regional warehouse, does not differ much among the days of the week. Actually when the daily truck requirements are rounded, the same integer value is obtained. This shows that the model works as intended. One can see that the number of SKUs to be replenished are not distributed evenly among the replenishment days. This is due to the differences in the amount of demand for different SKUs. On day-4 only 17 SKUs are replenished, but the total number of trucks required is the same with day-5, where 52 SKUs are replenished.

Table 5.2 Results of the Truck Requirement Balancing and SKU Grouping Module

		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Truck requirement of	Regional w/h 1	2.69	2.71	2.71	2.69	2.72	2.71
	Regional w/h 2	1.20	1.21	1.19	1.19	1.20	1.19
	Regional w/h 3	6.24	6.24	6.23	6.21	6.24	6.23
	Regional w/h 4	2.79	2.79	2.79	2.77	2.79	2.79
	Regional w/h 5	1.41	1.42	1.41	1.40	1.42	1.40
	Total	14.33	14.36	14.34	14.25	14.36	14.32
# of SKUs replenished		34	36	37	17	52	41

The number of trucks are not forced to take on integer values in this module. However, the third module and the experimentation of the system requires the number of trucks to be integers. The total number of trucks required is 15 when rounded up to the nearest integer. If we round up the truck requirement of every regional warehouse and then get the sum, the truck requirement is 17 per day. However, when 17 trucks are used, the utilization is lower. Therefore, the daily number of trucks available for shipments between the central warehouse and the regional warehouses is taken as 15 in the experimentation, to have a high utilization. The usage of mean demand data and the fact that a truck can only go to one regional warehouse will cause a constraint for the system.

The first two modules of the proposed approach, provide the inputs of the system and the simulation. However, the third module is the part of the simulation of the system with transportation constraints. Allocation of the inventories at the central warehouse to regional warehouses is performed by Shipment Consolidation and Truck Allocation Module. This is one of the differences of the experiment with transportation constraints from the simulation of the case without transportation constraints.

Another difference is in the inventory review and replenishment part of the simulation. Due to the palletized shipment constraint, some parameters of the system must be converted to units of pallets. As mentioned above, the order-up-to-levels and rationing fractions used in the case with transportation constraints are the same with the ones used in the no constraint case. However, these order-up-to-levels are in units of parcels, whereas the replenishments are done in pallets. Therefore, two different order-up-to-level parameters are used in the experimentation of the system, with transportation constraints. The first one, S_{ij}, is in units of parcels and equals to the value found by the Inventory Control Parameters Setting Module. The second one, Sij′, equals to the number of pallets equivalent of S_{ij}, rounded-up to the next integer. For example, if the number of parcels on a pallet of an SKU equals to 30 and the order-up-to-level in units of parcels, S_{ij}, equals to 100, then the order-up-to-level in units of pallets, Sij′, equals to 4. As can be seen, Sij′ is always greater than S_{ij}, in units of parcels. Thus, there can be more inventory for an SKU than the order-up-to-level of that SKU at a warehouse at any time.

Since the flow of goods between the two echelons of the network is in units of pallets, regional warehouse requirements must also be expressed in pallets. Therefore, the inventory positions of SKUs in warehouses, must also be seen in two different units: parcels and pallets. The conversion of the inventory position in parcels to the one in units of pallets is performed as follows during the simulation: if the inventory position of an SKU before replenishment in units of parcels, I_{ij}, is less than the order-up-to-level in units of parcels, S_{ij}, then the number of pallets equivalent of the inventory position is found and rounded-down to the biggest integer. If the inventory position in units of parcels, I_{ij}, is higher than the order-up-to-level in units of parcels, S_{ij}, then the number of pallets equivalent of the inventory position is calculated and rounded-up to the smallest integer. With this process, the inventory position in units of pallets, I_{ij}', is obtained. When the order amounts are determined during the review process and the truck loadings and assignments are made by the Shipment Consolidation and Truck Allocation Module, order-up-to-levels in pallets, Sij', and inventory positions in units of pallets, I_{ij}', are used.

The customer orders are still in units of parcels and the physical inventory is still kept track of in units of parcels. Although the Shipment Consolidation and Truck Allocation Module determines the shipment amounts in units of pallets, the inventory updates are done in units of parcels.

Shipment Consolidation and Truck Allocation Module requires still another parameter which is the ‘importance’ factors of the regional warehouses, A_i. The constraints of the transportation system are rationed among the regional warehouses according to this parameter. As mentioned in the previous chapter, for a regional warehouse for which the fill rate is much more important than it is for the other regional warehouses, its factor is relatively higher. The total yearly demand at the regional warehouses are observed and the regional warehouses are ranked according to this demand data. Also the regions where the competition is more fierce and stockout is more detrimental are determined. The strategic importances of these regions are higher. According to the strategic importances of the regions and the magnitude of the customer demands, importance factors are determined. Since stockout is more harmful than excess inventory, importance factors, A_i are set more than 0.5, as A_i is the factor of penalizing shortage and $(1-A_i)$ is the factor of penalizing surplus. Importance factors are given in Table 5.3.

Table 5.3 Importance Factors and Percent of Total Demand Observed in Regional Warehouses

	A_i	% of total demand
Regional w/h 1	0.7	11.6%
Regional w/h 2	0.6	5.1%
Regional w/h 3	0.9	26.8%
Regional w/h 4	0.9	12.0%
Regional w/h 5	0.7	6.1%
Regional w/h 6	0.9	38.4%

Since regional warehouse-6 is located at the same place with the plant warehouses, the constraints linking the shipment amounts with the truck capacity and the number of available trucks is relaxed for that regional warehouse while simulating the system.

The proposed system is simulated for 90% and 95% target fill rates, with the transportation constraints. When the target fill rate is 90%, the average inventory in the system is calculated as 4094 tons. The value of this amount of average inventory is 20,116,000 YTL. The average fill rate for all SKUs and for all regional warehouses is obtained as 92.53%. The deviation of the overall average fill rate is 2.8% from the target fill rate. This deviation is greater than the no transportation constraint case. Furthermore, absolute deviations of the actual fill rates, from the target fill rate for SKUs in time are much higher. The histogram of actual – target fill rate deviation for a number of SKUs, when target fill rate equals 90%, is given in Figure 5.4.

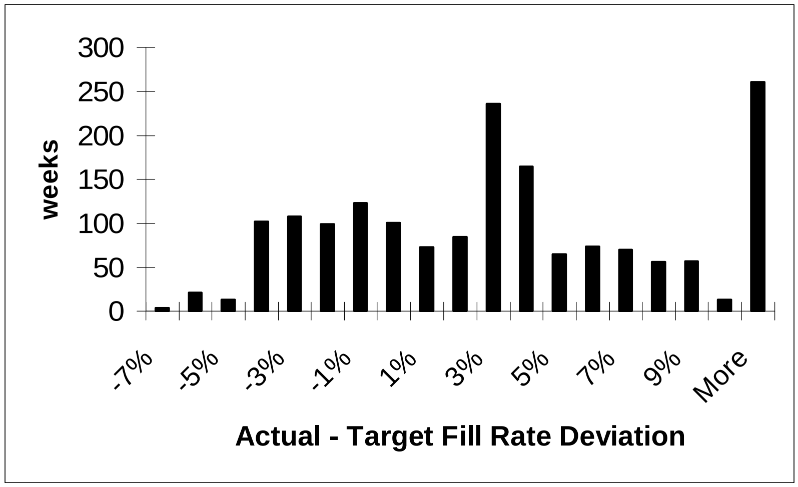

Figure 5.4 Histogram of Actual – Target Fill Rate Deviation for 90% Target Fill Rate when Transportation Constraints Exist

Absolute deviation of 11% is observed many times, which equals to an actual fill rate of 100%. Actual fill rates of 100% are especially observed for the SKUs, whose average demand is low and has an excess inventory for most of the time due to the constraint of shipments on pallets. Also, both the suplus and shortage occasions as a result of full truckload shipments, affect the robustness of the actual fill rates. The deviations of actual fill rate from the target fill rate is generally on the positive side and the average inventory held is also higher than the case of no transportation constraints.

Truck utilization rate, which is calculated as the ratio between the number of trucks sent to the regional warehouses and the available number of trucks, is found as 94% on the average. The average inventory held is still less than the existing system and the actual fill rate is higher.

Simulation of the system with 95% target fill rate, resulted with an average inventory of 4514 tons (22,450,000 YTL). The average actual fill rate of the system is calculated as 95.77% which is 0.8% higher than the target fill rate. Actual fill rates deviate much in time as it is for the case with 90% target fill rate. Although the objective is to have a 95% fill rate, 100% fill rates are observed many times during the simulation. The histogram showing the deviations from the 95% target fill rate for a group of SKUs can be seen in Figure 5.5. Truck utilization is found as 92% for this case.

Higher actual fill rates observed in the case with transportation constraints can be explained by shipment of SKUs on pallets and as a result having higher inventories than the order-up-to levels at the regional warehouses. Also, shipments more than the requirements of the inventory control system are made, because of the constraint that trucks must go with full truckloads. Although the model restricts the shipment of the required amounts due to the limited number of trucks available, this does not affect the system too much. The effect of sending less is absorbed in the system on the average, since the decision to send less is given according to the equity principle, that is, sharing the limited capacity fairly among both the SKUs and regional warehouses.

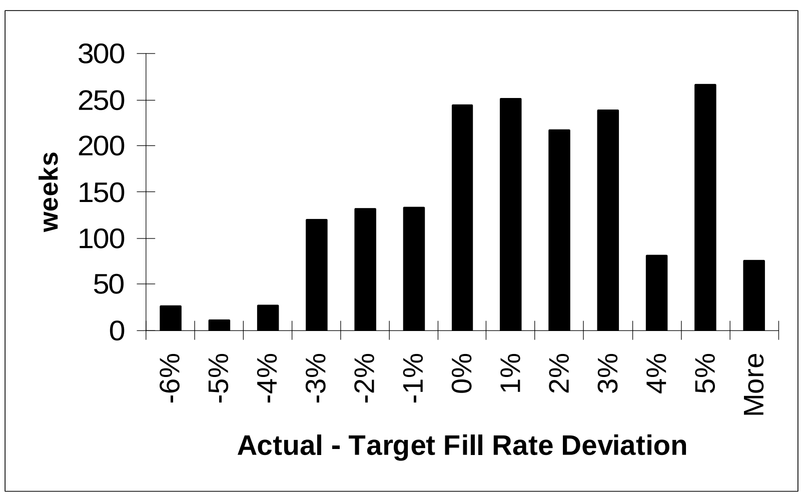

Figure 5.5 Histogram of Actual – Target Fill Rate Deviation for 95% Target Fill Rate when Transportation Constraints Exist

Another observation is that, the fleet size becomes a scarce resource especially at the first weeks of a month, just after the high demand at the end of the previous month. Shortage occasions occur at the beginning of the months, since more amount is required to bring the inventory positions of the regional warehouses to the order-up-to-levels which are the same throughout the month. Although the order-up-to levels can not be reached at the regional warehouses at these times, reasonable fill rates are observed, since the demand of customers is also low at the same time. Although demand is increasing towards the end of the month, the usage of the limited number of trucks prevents the truck utilization from varying in a month. Since, the number of trucks is determined according to the mean demand, the order-up-to-levels at the regional warehouses can be reached by the second half of the month. By this time, only the amounts limited with the available truck capacity can be shipped. Thus, the small amount of requirement after the low demand at the beginning of the month increases, as a result of sending less than the requirement the period before. By this way, the number of trucks sent to the regional warehouses is evenly distributed in a month. If there is no limit for the number of trucks available, more trucks will be sent at the beginning of the months, after the high demand observed at the end of the previous month and less trucks will be sent after the low demand at the beginning of the months. This will result in low and varying truck utilization.

Presence of transportation constraints also causes the average fill rate to vary among the regional warehouses. Regional warehouse–6, which is not affected by the transportation constraints, has on the average closest actual fill rates to the target fill rate. Higher actual fill rates are observed at regional warehouse-3 and regional warehouse-4 for both cases. This result is not surprising since both warehouses have the highest importance factors. Due to the high importance factors, shipments less than the requirements are penalized more than the other regional warehouses, while the excess shipment penalty is lower. Regional warehouse-1 observed the least actual fill rate for the case of 95% target , although the importance factor of regional warehouse-2 is lower. This may be due to the demand characteristics. Average actual fill rates at the regional warehouses are depicted in Table 5.4 and Table 5.5 for 90% target fill rate and 95% target fill rate, respectively.

Table 5.4 Average Actual Fill Rates at Reagional Warehouses

When Target Fill Rate =90%

	Target Fill Rate	Average Actual Fill Rate
Regional w/h 1	90%	91.74%
Regional w/h 2	90%	91.13%
Regional w/h 3	90%	94.52%
Regional w/h 4	90%	94.07%
Regional w/h 5	90%	92.69%
Regional w/h 6	90%	90.07%

Table 5.5 Average Actual Fill Rates at Reagional Warehouses

When Target Fill Rate =95%

	Target Fill Rate	Average Actual Fill Rate
Regional w/h 1	95%	94.74%
Regional w/h 2	95%	94.86%
Regional w/h 3	95%	97.36%
Regional w/h 4	95%	96.88%
Regional w/h 5	95%	95.43%
Regional w/h 6	95%	95.13%

The comparison of the existing system with the proposed system under transportation constraints for 90% and 95% target fill rates is given in Table 5.4.

Table 5.6 Comparison of Existing System with Proposed System When Transportation Constraints Exist

	Avg. Inventory (tons)	Target Fill Rate	Avg. Actual Fill Rate
Existing System	4200		90%
Proposed system with 90% target fill rate	4094	90%	92.53%
Proposed system with 95% target fill rate	4514	95%	95.77%

The average inventory increases in the proposed system when transportation constraints are included in the experimentation (more realistic case). However, in the simulation with 90% target fill rate, the average inventory held is still less than the average inventory in the existing system, where the fill rate is 90%. Moreover, the average actual fill rate increases to 92.53%. Higher fill rate with less inventory shows that the right composition and amounts of SKUs are held in the inventory, as a result of the pull structure (demand driven) present in the proposed system. However, the existing incentive system is still a problem from the point of view of inventory reduction. If a method to distribute the demand of the customers uniformly through the month is found, the same target fill rates can be reached with much less inventory. Another improvement may be to apply the vendor managed inventory (VMI) system at the distributors of the company to extend the pull system in the supply chain so as to include the customers as well and to distribute the demand at the regional warehouses more uniformly over time.

Response time to customers is defined as one of the performance measures of the inventory-distribution system. Actually, together with the fill rate, this is one of the most important performance measures in FMCG supply chains.

Inclusion of the regional warehouses between the customers of the company and the plant warehouses, decreases the distance between the company and its customers. In the existing single-echelon inventory-distribution system network, the average distance between the cities where the customers are located and the city where the plants of the company is located is 742.5 km's. Also there are customers which are more than 1000 km's far from the plant warehouses. In the proposed two-echelon network, where the customers are served by 6 regional warehouses located in different cities of Türkiye, the average distance from the warehouses of the company to the cities where the customers are located reduces down to 315 km's. The maximum distance is below 800 km.'s and distances are negligible for the customers in the same city with the regional warehouses of the company. Distances between the company and the cities of the customers can be seen in Figure 5.6.

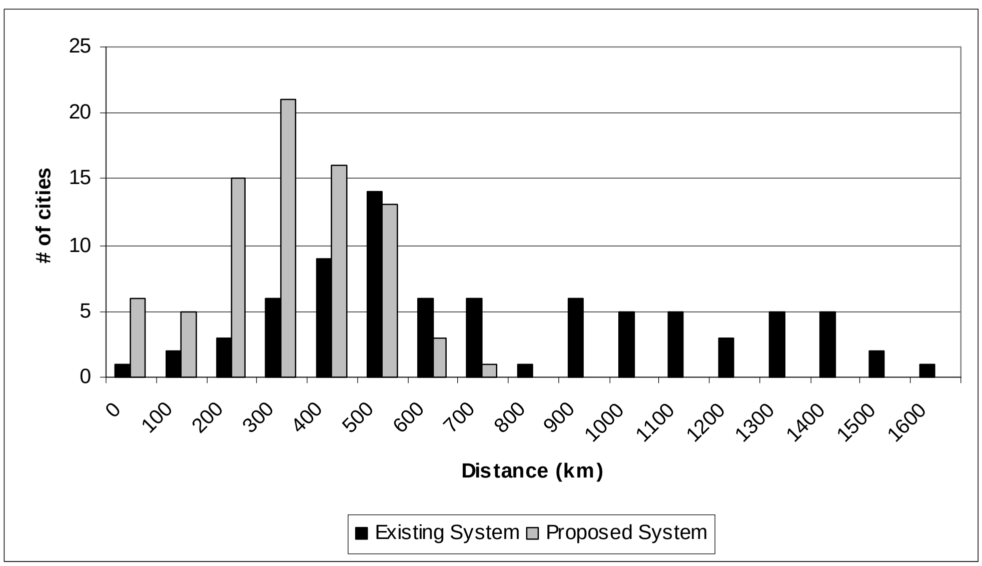

Figure 5.6 Distances Between the Cities of Customers and the Warehouses of the Company in Existing and Proposed Systems

As can be seen, the response time to customers is considerably decreased with the proposed system. Furthermore, the regional warehouses are located at the cities where the demand is highest in that region and the main depots of the national chain markets exist. This results in the demand weighted response time to be much smaller.

Warehouse related costs constitute a major part of the total logistics cost in an inventory distribution system, especially when regional warehouses exist in the system. Warehouse related costs can be seperated into two, as the leasing cost and the operating costs. According to the order-up-to-levels calculated for the regional warehouses and the assumption that 3.26 m^3 of volume is required to store 1 m^3 of goods, the volumes shown in Table 5.7 are calculated as the required regional warehouse sizes.

Yearly leasing costs are found for the cities where the regional warehouses are located. When the loading and unloading areas are considered in addition to the required volumes of regional warehouse, the regional warehouse leasing cost is found as 874,000 YTL per year. In this calculation, no leasing cost is considered for regional warehouse-6, since this will be located in the plant warehouses.

Table 5.7 Sizes of the Regional Warehouses

	Size (m^3)
Regional w/h 1	8288
Regional w/h 2	5290
Regional w/h 3	17960
Regional w/h 4	8590
Regional w/h 5	5447
Regional w/h 6	21916

The number of personnel and the equipment required for the 5 regional warehouses can be seen in Table 5.8. According to these requirements, the operating cost for the regional warehouses is calculated to be 1,012,000 YTL per year. Thus, by opening 6 regional warehouses, warehouse related cost in the system increases by 1,886,000 YTL per year.

Table 5.8 Personnel and Equipment Requirements of Regional Warehouses

	Regional w/h 1	Regional w/h 2	Regional w/h 3	Regional w/h 4	Regional w/h 5
PERSONNEL					
Operation Chief	1	1	1	1	1
Loading/Unloading Official	1	1	2	1	1
w/h Entrance Official	1	0	1	1	0
Security Guard	2	2	2	2	2
Shipment Official	1	1	1	1	1
Forklift Operator, Worker	6	4	15	6	4
EQUIPMENT					
Forklift	1	1	2	2	1
Transpallet	2	2	4	4	2
Computer	2	2	2	2	2

The major cost element in the inventory-distribution system is the transportation cost in this industry. As mentioned before, when the network is changed to a two-echelon structure, the greatest savings in terms of cost is obtained in the transportation costs. The existence of regional warehouses gives the opportunity to make bulk shipments from the plant warehouses to the regional warehouses by the high-capacity long-trucks, which are cheaper than the ordinary trucks. Since, for a considerable part of the distance from the company to customers, goods are shipped with a cheaper transportation mode, transportation cost of the system decreases. When compared to the existing system, transportation cost decreases by 3,140,000 YTL per year with the proposed inventory-distribution system when target fill rate is 90%.

When the proposed two-echelon system is evaluated in terms of the performance measures defined, it can be seen that the proposed system is much more advantageous than the existing system. The cost reduction obtained from the transportation mode change outperforms the additional cost arising from opening regional warehouses. Inventory holding cost decreases since the average inventory held in the system is less than the existing system. Meanwhile, the fill rate to customers increases by 2.53% and the response time reduction is very high.

5.6 Summary of Results

The results obtained in the retrospective experimentation of the proposed system with and without transportation constraints are summarized below.

- When no transportation constraint exists, slightly less average actual fill rates are observed than the target fill rate. Although the average performance is good in terms of the target fill rate achievement, the deviations from the target fill rate vary in time. The deviations should have been concentrated on the interval -1% - 1%, however, deviations outside this range are observed.

- The reason for varying deviations can be explained by the distribution of demand in a month, due to the incentive system used for the distributors. Since demand increases towards the end of the month, higher and lower fill rates are observed at the beginning and at the end of the months respectively. If a method to distribute the demand evenly in a month is used or adapted, the robustness of the system in terms of fill rate can be improved.

- The proposed system gives better results when the target fill rate is higher, in terms of average and absolute deviations of the actual fill rate from the target fill rate.

- The retrospective simulation shows that, almost the same fill rate can be achieved with 9.4% less inventory, in the proposed system when no transportation constraints exists. Moreover, by holding the same amount of inventory with the existing system, fill rates can be increased from 90% to 94.6% on the average. This can be explained by the demand driven, pull structure of the proposed system, instead of forecast driven push structure inherent in the existing system.

- When transportation constraints are included in the retrospective simulation, the average actual fill rate increases compared to the no transportation constraints case. Higher fill rates are obtained because of full truckload and palletized shipments.

- Palletized shipments and shipments more or less than the requirements of the inventory system due to the transportation constraints, result in the deviation of the actual fill rates much more in this case. Actual fill rates of 100% are observed, although the target values are 90% or 95%. Absolute deviations of 11% and 5% are observed for the 90% and 95% target fill rates respectively.

- Due to the importance factors given to the regional warehouses, different average actual fill rates are observed at different regional warehouses. Higher actual fill rates are obtained at the regions where stockout may be much more detrimental to the company.

- Although the average inventory in the system increases with the presence of palletized shipments and transportation constraints, still less inventory is held than the existing system for the same level of target fill rate. For the 90% target fill rate, the value of the average inventory in the proposed system with transportation constraints is 584,000 YTL less than the value of the average inventory in the existing system. Moreover, the average actual fill rate observed is 2.53% higher than the fill rate in the existing system. However, this time the actual fill rate can not be increased to 95%, with the same level of inventory as in the existing system.

- Response time to customers decreases with the proposed two-echelon system. Average distance to the customers from the warehouses decreases from 742 km.'s to 315 km.'s. All of the customers are within the 700 km. area from the warehouses of the company.

- Locating 6 regional warehouses between the customers and the plants of the company results in an additional cost of 1,886,000 YTL per year. However, with the opportunity to make bulk shipments to the regional warehouses, yearly transportation cost decreases by 3,140,000 YTL.

CHAPTER 6

CONCLUSION AND DIRECTIONS FOR FUTURE RESEARCH

In this research, inventory-distribution system of a company operating in the Fast Moving Consumer Goods (FMCG) industry is analyzed. After a previous study performed in the company, it is decided to change the distribution network of the company, by opening six regional warehouses that will operate as distribution centers between the company and its customers. With this new logistics network structure, the system becomes a two-echelon inventory-distribution system and a method to control and replenish the inventories in the system is required.

The system considered in this study differs from the other studies in the field of multi-echelon and two-echelon inventory systems. There exist some transportation constraints affecting the replenishment of inventories in the second echelon and also there are multiple items replenished together. Therefore, an approach consisting of three modules, that operate in a hierarchical manner, is developed for the inventory-distribution system with these specific transportation constraints.

The first module of the proposed system determines the inventory control policy with its control parameters, as the order-up-to-levels and rationing fractions for the central and regional warehouses using the approach of van der Heijden (1997). In order to overcome the seasonality problems, three groups of months are formed for which the demand characteristics are similar. The second module of the system groups the SKUs and assigns them replenishment days with the objective of balancing the truck requirements for the replenishment of inventories throughout a week by means of an IP model. These two modules are designed to work at the tactical level and run every year or a season. The third module works at the operational level and makes the truck allocations to the regional warehouses and decides on the replenishment amounts for each SKU for each regional warehouse. For this third module, a MIP model is constructed to determine the optimal vehicle allocation and order replenishments under the transportation constraints, so as to minimize the violation of the inventory control policy determined by the first module.

The proposed approach is experimented with retrospective data of the company, with and without the existence of transportation constraints, for two different target fill rates.

The experimentation with no transportation constraints, only the first module of the approach resulted with average actual fill rates which are slightly less than the target fill rates. However, the actual fill rates varied within a larger range than expected. This high variation is explained by the incentive system used for the distributors of the company, which causes the demand to concentrate on the last weeks of a month. Better results are found, when the target fill rate is higher. Another observation was that the same target level is obtained with less inventory in the proposed system than the existing system.

The experimentation of the proposed system with the transportation constraints resulted with average actual fill rates which are higher than the target fill rates. For this case, the variations observed in the actual fill rates are higher. Since the replenishment amounts are affected by the transportation constraints and shipment amounts are in units of pallets, this high variation in the fill rates is reasonable. Another observation was that the average inventory levels calculated are higher for the case with transportation constraints than the no transportation constraints case. However, when compared to the existing system, higher average actual fill rate is observed by holding still slightly less inventory than the existing system. Normally the total inventory in the system should have increased with the addition of the regional warehouses, but the demand driven pull structure inherent in the proposed system enables to hold the right composition and amount of SKUs in the inventory.

The advantages of the proposed system are not limited with the higher fill rate observed, despite holding less inventory. The average distance between the customers and the warehouses of the company is halved, which in turn reduces the response time to the customers. This is very important for a company in the FMCG industry. Moreover, the transportation cost decreases, as a result of the bulk shipments from the plant warehouses to the regional warehouses. Although an additional cost emerges by opening regional warehouses, this cost is less than the cost advantage obtained from transportation. As a result it can be said that, with the proposed inventory-distribution system, better customer service level can be obtained with less logistics costs.

The proposed inventory-distribution system is very much affected by the orders coming from the customers. The robustness of the system in terms of fill rate, will be better and the same fill rates can be achieved with much less inventory, if the orders are coming from the customers uniformly in a month. The impact of uniformly distributed demand on the performance of the proposed inventory-distribution system and the benefits can be observed by evaluating the proposed system with more sterilized generated data. Also, a future study that aims at distributing the demand uniformly in a month is strongly required. The incentive system applied for the customers can be the first improvement area.

Another future study can be an inventory-distribution system design with correlated demand structure for a similar environment where transportation constraints exist. Also, the case where lateral transshipments are allowed can be studied. In that case inventory misplacement and stockout occasions may decrease.

Other possible future studies may be on the operations between the regional warehouses and the customers. An order receiving and shipment scheduling system can be designed, to have a more efficient and effective logistics system between the regional warehouses and the customers. Also applying vendor managed inventory (VMI) at the customers can bring many more advantages to the distribution system of the company and it is worthwhile to study the effects of VMI on the system.

The proposed system gives production orders to the plants for the coming week. However, production planning is performed for a twelve-week rolling horizon. Therefore, a system can be designed to give forecasts on the future central warehouse orders, based on the working characteristics of the proposed system.

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