HIERARCHICAL PRODUCTION PLANNING APPROACH TO SUPPLY CHAIN MANAGEMENT

(TEDARİK ZİNCİRİ YÖNETİMİNDE
HİYERARŞİK ÜRETİM PLANLAMASI YAKLAŞIMI)

by

Orhan İlker KOLAK, B.S.

Thesis

Submitted in Partial Fulfillment

of the Requirements

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A supply chain is a network of installations that assures functions of supplying raw materials, transporting these raw materials, transforming these raw materials to parts then end product, distribution of end product to clients, and finally after sale service, recycling and scrap products at the end of life cycle. Consisting of many parts, a supply chain may be a very complex system to be solved with monolithic approach. So in this study, we have adopted a hierarchical approach to solve these kinds of problem. Hierarchical approach is first proposed by Hax and Meal to divide global problem to simpler sub problems in order to reduce calculation times. Thus, integration of hierarchical production planning to supply chain management problems constitutes the subject of this study.

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Abstract

A supply chain is a network of installations that assures functions of supplying raw materials, transporting these raw materials, transforming these raw materials to parts then end product, distribution of end product to clients, and finally after sale service, recycling and scrap products at the end of life cycle.

Supply chain is composed of an ensemble of processes and relations between different enterprises which business partners are aiming to optimize product displacement in the space and time with the goal of answering more efficiently to requirements of final consumer and principally at lowest delay and cost possible. In effect, today's enterprises does not suffice alone to answer the variable requirements of market provoked by competition. Thus, they reunite around common objectives connected at the same time to market and entire supply chain itself and it forms a complex and difficult to manage system which constitute of many plants for manufacturing many products, of many warehouses, of many distribution centers and of many clients.

The fundamental characteristic which provokes the evident complexity of relations between the members of the supply chain is that the system precisely behaves as a chain. This signifies that each link has an impact on the remaining of the chain, positively and negatively. Thus, all ruptures of merchandises at a supplier will repeat until the final client; as all changes and incertitude of parameters such as the demand, lead times, capacity etc., provoke different responses at each link. In effect, if a part of the chain doesn't assure correctly its function, the end product can't be available at time, at the desired quality and cost. Then, the importance of a well supply chain management is no longer to demonstrate.

A supply chain may contain many elements and the relations between them may be very complex. This conducts supply chains, for example, to develop mathematical models to

determine the production quantities, the time concerning the production until the delivery to final consumer, the quality level to be respected etc., taking into account the constraints of supplying, producing, stocking and distribution along the chain at the same time. Since the supply chains are systems constituting of many variables and parameters, a monolithic approach won't be appropriate, in term of efficiency, to model them.

In this study we will focus on the Hierarchical Production Planning approach to solve Supply Chain Management problems. The hierarchical planning is a convenient model to plan and manage the incertitude and complexity inherited in the nature of supply chain and thus to minimize the costs and decrease response time to market.

Hierarchical approach is proposed as an alternative to the approach monolithic. It is proposed by Hax and Meal, for the first time, to solve complex production planning problems. In the hierarchical approach, global problem is decomposed to simpler sub-problems. These sub-problems are hierarchically related to each other. All of these sub-problems require a planning and modeling that corresponds to a decision making layer. So, establishing a hierarchical production planning system means choosing a number of decision making layers, a model for each layer and finally a method to coordinate the decisions flow and information feedback between the layers.

Calculation time is shorter then monolithic approach. But, using such an approach, finding a sub-optimal solution is accepted at the beginning. The performance of the result or the proximity of the solution to the optimal will depend essentially according to the hierarchy choice. The most important gain of hierarchical approach is the simplicity because with such an approach, decisions are taken step by step in a successive fashion descending the established hierarchy. These decisions obtained by the hierarchical planning are taken in a way that aggregated decisions imposes constraints to the detailed decisions and in return detailed decisions returns a feedback to evaluate the quality of the aggregate decision. It is evident that taking efficient decisions requires an efficient modeling of the decision hierarchy.

In the remaining of the study the structure of decision making is introduced. Several decision layers and historical developments are presented. Hierarchical Production Planning is studied more deeply and several techniques are introduced. Also inconveniences are discussed and methods to overcome such inconveniences are evaluated and an illustrative example is given to better understand these inconveniences.

Then, a model has been formed to solve a general supply chain problem consisting of several stages with several facilities. More than one product types are considered. Also shipping costs are taken into account building this model. Our objective on this model was to minimize total costs. We have considered mainly three costs namely, production, inventory and finally shipping. As the problem is presented, we have applied the hierarchical production planning approach to solve this problem. We have divided the problem into two sub-problems. In the first model we searched to find an aggregate solution to the problem and in the second model we disaggregated this solution to find a detailed model. For the disaggregation we only had to look for the first period of the problem which reduced dramatically amount of required calculations. At the end we have obtained a model which finds an adequate solution in a reasonable amount of time. This solution being sub optimal was acceptable in most of the cases. Also we have overcome uncertainty and variations using this approach.

Finally at the end of the study, we have constructed a specific problem, and solved it using the model constructed previously. We described our model and objectives also supplied the results obtained. To solve the problem we have used two mathematical models and solved them using computer. After solving the first model we passed required results to the second one manually and solved the second one. Thus we have obtained the final results.

Using the hierarchical production planning approach to solve supply chain management enabled us to find a way to solve complex problems in a reasonable amount of time. This method should have lots of application in real world situations. In today's competitive environment time is very precious and the methods provided in this study will let use it more efficiently.

Résumé

Une chaîne d'approvisionnements est un réseau d’installations qui assure des fonctions d'obtention des matières premières, transportions de ces matières premières, transformation de ces matières première au produit final, distribution du produit final aux clients, et finalement après service de vente, la réutilisation et disposition de matériel à la fin de sa vie.

La chaîne d'approvisionnements se compose d'ensemble de processus et de relations entre les différentes entreprises qui visent à optimiser le déplacement de produit dans l'espace et le temps. Le but est de répondre plus efficacement aux conditions du consommateur final et principalement au plus vite et au moindre coût possible. En effet, les entreprises d'aujourd'hui ne suffisent pas à répondre aux conditions variables du marché provoquées par la concurrence. Ainsi, elles réunissent autour des objectifs communs reliés en même temps au marché et la chaîne d'approvisionnements entière elle-même et forme un complexe et difficile system à contrôler qui constitue de plusieurs usines pour fabriquer plusieurs produits, de plusieurs d'entrepôts, de plusieurs centres de distribution et de plusieurs clients.

La caractéristique fondamentale qui provoque la complexité évidente des relations entre les membres de la chaîne d'approvisionnements est que le système se comporte précisément comme une chaîne. Ceci signifie que chaque lien a un impact sur le reste de la chaîne, positivement et négativement. Ainsi, toutes les ruptures chez un fournisseur répéteront jusqu'au client final ; en tant que tous les changements et incertitude des paramètres tels que la demande, les délais d'exécution, la capacité etc., provoquent les différentes réponses à chaque lien. En effet, si une partie de la chaîne n'assure pas correctement sa fonction, le produit final ne peut pas être disponible au temps, à la qualité et au coût désirés.

Une chaîne d'approvisionnements peut contenir plusieurs d'éléments et les relations entre eux peuvent être très complexes. Ceci conduit les managers des chaînes d'approvisionnements, par exemple, à développer des modèles mathématiques pour déterminer les quantités de production, l'heure au sujet de la production jusqu'à la livraison au consommateur final, le niveau de qualité à respecté, etc tenant compte des contraintes de l'approvisionnement, de la production, de stockage et de la distribution le long de la chaîne. Puisque les chaînes d'approvisionnements sont constituées de systèmes de plusieurs variables et de paramètres, une approche monolithique ne sera pas convenaient, dans le contexte de l'efficacité, pour les modeler.

Dans cette étude nous nous concentrerons sur l'approche hiérarchique de planification de la production pour résoudre des problèmes de gestion de chaîne d'approvisionnements. La planification hiérarchique est un modèle commode pour projeter et contrôler l'incertitude et la complexité héritées dans la nature de la chaîne d'approvisionnements et ainsi pour réduire au minimum les coûts et pour diminuer le délai réponse au marché.

On propose l'approche hiérarchique comme une alternative à l'approche monolithique. Hax et Meal l'ont proposé, pour la première fois, pour résoudre des problèmes complexes de planification de la production. Dans l'approche hiérarchique, le problème global est décomposé en sous-problèmes plus simples. Ces sous-problèmes sont hiérarchiquement reliés entre eux. Tous ces sous-problèmes exigent une planification et modeler cela correspond à une couche de prise de décision.

Le temps de calcul est plus courte comparé à une approche monolithique. Mais, employant une telle approche, trouver une solution suboptimale est accepté dès le début. L'exécution du résultat ou la proximité de la solution à la valeur optimale dépend essentiellement selon le choix de hiérarchie. Le gain le plus important de l'approche hiérarchique est la simplicité parce qu'avec une telle approche, des décisions sont prises point par point d'une mode successive descendant la hiérarchie établie. Il est évident que la prise des décisions efficaces exige modéliser efficacement la hiérarchie de décision.

Dans le reste de l'étude la structure de la prise de décision est présentée. Les niveaux de décision et le développement historique sont présentés. La planification de la production hiérarchique est étudiée plus profondément et plusieurs techniques sont présentées. En outre des complications sont discutés et des méthodes pour surmonter de tels complications sont évaluées et un exemple d'illustration est donné pour comprendre mieux ces complications.

Puis, un modèle a été formé pour résoudre un problème général de chaîne d'approvisionnements se composant de plusieurs étapes avec plusieurs équipements. Nous avons considéré principalement trois coûts notamment, production, stock et finalement transportation. Après avoir présenté le problème, nous avons appliqué l'approche hiérarchique de planification de la production pour le résoudre. Nous avons divisé le problème en deux sous-problèmes. Dans le premier modèle agrégé, nous avons sollicité une solution globale au problème et dans le deuxième modèle désagrégé, nous avons détaillé cette solution. Enfin nous avons obtenu un modèle qui trouve une solution acceptable en un temps raisonnable. Cette solution étant suboptimal était acceptable dans la plupart des caisses. En outre nous avons surmonté l'incertitude et les variations en utilisant cette approche.

Enfin à la fin de l'étude, nous avons construit un problème spécifique, et l'avons résolu employant le modèle construit précédemment. Nous avons décrit notre modèle et également fourni les résultats obtenus. Pour résoudre le problème nous avons employé deux modèles mathématiques et les avons résolus à l’aide de l’ordinateur.

L'utilisation de l'approche hiérarchique de planification de la production pour résoudre la gestion de chaîne d'approvisionnements nous a permise de trouver une manière de résoudre des problèmes complexes dans une quantité de temps raisonnable. Cette méthode devrait avoir un bon nombre d'application dans de vraies situations du monde. Dans la condition de concurrence d'aujourd'hui le temps est très précieux et les méthodes fournies dans cette étude permettront de l’utiliser plus efficacement.

Özet

Tedarik zinciri, hammadde ihtiyacı, bu hammadenin taşınması, hammaddenin önce yarı mamule ardından son ürüne dönüştürülmesi, son ürünün müşterilere dağıtılması ve son olarak satış sonrası hizmet, geri dönüşüm ve ürünün ömrünün sonunda atıklarının yönetimi işlevlerini yerine getiren bir ağ yapısıdır.

Tedarik zinciri, birçok farklı şirket arasındaki süreç ve ilişkilerden oluşan bir kümedir. İş partnerlerinin amacı, ürünlerin uzayda ve zaman içinde yer değiştirmelirini en iyilemektir. Bunu yapmaktaki amaç, ilk olarak düşük gecikme ve maliyet ile, müşterinin son ürün ihtiyaçlarına daha etkin olarak cevap vermektir. Aslında, günümüz şirketleri, sadece yüksek rekabet halindeki pazarın değişken ihtiyaçlarını karşılamakla yetinmez. Bu durumda, pazar ve tedarik zincirinin kendisine bağlı ortak hedefleri etrafında birleşirler, ayrıca karmaşık ve yönetmesi zor bir sistem oluştururlar. Bu sistem birçok ürünü üretmek için çok sayıda fabrika, çok sayıda depo, çok sayıda dağıtım merkezi ve çok sayıda müşteriden oluşabilir.

Tedarik zinciri üyeleri arasındaki ilişkinin karmaşıklığını meydana getiren ana etmen, sistemin tam bir zincir gibi işlemesidir. Bu, zincirdeki her halkanın zincirin geri kalanını olumlu veya olumsuz etkilemesininden dolayıdır. Bu durumda, tedarikçide meydana gelecek tüm ürün kesintileri son müşteriye kadar devam edecektir, çünkü talep, tedarik süreci, kapasite vesaire gibi parametrelerdeki tüm değişme ve belirsizlikler, her halkada farklı tepkilere yol açacaktır. Zincirin bir halkası işlevlerini doğru yerine getirmiyorsa, son ürün, zamanında, istenen kalite ve maliyette elde edilemez. Böylece, bir tedarik zincirinin iyi yönetilmesinin önemi ortaya çıkmaktadır.

Tedarik zinciri çok sayıda üyeden oluşabilir ve bu üyeler arasındaki ilişkiler çok karmaşık olabilir. Bu durum, tedarik zincirleri yöneticisini, örneğin üretim miktarları, son üreticiye ulaşana kadarki zamanı, önemsenen kalite seviyesini vesaire; tedarik,

üretim, stoklama ve dağıtım kısıtlarını gözeterek, tüm zinciri kapsayan bir matematik model geliştirmeye yönlendirir. Tedarik zincirleri, çok sayıda parametre ve değişkenden oluşan bir sistem olduğundan monolitik bir yaklaşımla modelleme etkinlik açısından çok uygun olmayacaktır.

Bu çalışmada biz, tedarik zinciri yönetimi problemlerinin çözülmesinde hiyerarşik üretim planlaması yaklaşına odaklandık. Hiyerarşik planlama, tedarik zincirinin doğasından gelen belirsizlik ve karmaşıklığı planlamakta ve yönetmekte uygun bir modeldir. Böylece masrafların düşmesinde ve pazara cevap verme süresinin azalmasında etkili olmaktadır.

Hiyerarşik yaklaşım, monolitik modele bir alternatif olarak ortaya atılmıştır. İlk kez, Hax ve Meal tarafından, karmaşık üretim planlama modellerini çözmek için önerilmiştir.

Hiyerarşik yaklaşımda, global model, daha basit alt problemlere ayrıştırılır. Bu alt problemler birbirleriyle hiyerarşik bir ilişki içindedirler. Tüm bu alt problemler, karar alma katmanlarına denk gelen planlama ve modellemelere ihtiyaç duyar. Öyleyse, hiyerarşik üretim planlama sistemi oluşturmak demek, birçok karar alma katmanı seçmek demektir. Her modele bir katman denk gelir. Katmanlar arası karar akışını ve bilgi geri dönüşünü koordine edecek bir metod oluşturulması gerekir.

Monolitik yaklaşıma göre hesaplama süreleri kısaltılmış olur. Fakat böyle bir yaklaşım benimsenerek, optimum altı bir sonuç bulunması en baştan kabullenilmiş olur. Sonuçların performansı veya çözümün optimuma yakınlığı temelde hiyerarşi seçimine göre değişir.

Hiyerarşik yaklaşımın en büyük kazancı basitliğidir çünkü, böyle bir yaklaşım ile kararlar, adım adım ve ardısıra gelen bir şekilde hiyerarşik katmanlarda aşağı inilerek alınır. Genelleştirilmiş çözümler, detaylı çözümlere, kısıtlar empoze eder, detaylı çözümler ise genelleştirilmiş çözümlerin sonuçlarını değerlendirmek amacıyla geri dönüş sağlarlar. Etkin bir karar alma için etkin karar hiyerarşisi modelinin gerekliliği bulunmaktadır.

Çalışmamızda, karar alma yapısı çeşitli karar katmanları ve tarihsel gelişimi ile incelenmiştir. Hiyerarşik üretim planması üzerinde derinlemesine çalışılmış ve çeşitli teknikler tanıtılmıştır. Ayrıca, uygunsuzluklar da tartışılmış ve bunların üstesinden gelme yöntemleri değerlendirilmiştir ve açıklayıcı bir örnek bu uygunsuzlukların daha iyi anlaşılması için verilmiştir.

Ardından, birçok aşamadan oluşan genel bir tedarik zinciri örneği kurulmuş ve bu örneği çözmeye yönelik bir model oluşturulmuştur. Birden fazla ürün çeşidi dikkate alınmıştır. Ayrıca bu modelde taşıma masrafları da göz önüne alınmıştır. Bu modelde amacımız toplam maliyetleri en azlamaktır. Asıl olarak üç maliyet üzerinde durulmuştur. Bunlar, üretim, stok, ve taşıma maliyetleridir. Problem sunulurken, hiyerarşik yapıda bir çözüm modeli de oluşturulmuştur. Problem iki alt modele ayrılmış, ilkinde genelleştirilmiş problem modeli oluşturulmuş ardından ikinci model ile genelleştirilmiş sonuçlar detaylandırılmıştır. Detaylı model için sadece ilk periyoda bakma gerekliliği gerekli hesaplama miktarını büyük ölçüde düşürmüştür. Sonuç olarak, uygun bir sonucu, kabul edilebilir bir zamanda bulan bir model oluşturulmuştur. Bu sonuç, optimal altı olmakla birlikte, çoğu durumda kabul edilebilirdir. Ayrıca bu yaklaşım ile, belirsizlik ve değişkenliğin üstesinden gelinmiştir.

Model oluşturulurken , örnek bir problem incelenmiş ve oluşturulan model ile çözülmüştür. Model ve amaçlar ile elde edilen sonuçlar incelenmiştir. Problemi çözmek için iki matematiksel model bilgisayar yardımı ile çözülmüştür. İlk model çözüldükten sonra sonuçlar ikinci modele aktarılmıştır. Sonuç olarak, en son çözüm bulunmuştur.

Tedarik zinciri yönetimine hiyerarşik üretim planlama yaklaşımı, karmaşık problemlere uygun bir sürede çözüm bulmamızı sağlamıştır. Bu yöntem gerçek dünyada birçok uygulama alanı bulabilir. Günümüz rekabetçi ortamında, zaman çok değerlidir ve bu çalışmada sunulan yöntem onu daha verimli kullanmayı sağlamaktadır.

1. Introduction

A supply chain is a network of suppliers, manufacturers and distributors. There exists generally a very complex relation between these elements of a supply chain. These elements should work in coordination in order to operate more efficiently. The coordination between several facilities in a supply chain is very crucial. As we will delve into more detail later, a little problem in a link of the chain would affect the entire chain. A supply chain may be consisted of many enterprises. In this case each enterprise should not try to optimize itself but should work as a team member which will allow the entire chain to operate more efficiently. As a result all of the members of the chain would result from this efficiency. [1]

As a supply chain can be a very complex system containing many facilities and relations it can be very difficult to study and optimize it. In a supply chain many factors should be taken into account. All of these factors will be presented with details later in this study. But the fact is solving a supply chain can be a very complex and time consuming problem.

Traditional monolithic approaches may let us find very good solutions but such approach may require very large processing powers and may need too much time. As time is precious in today's competitive environment decisions should be taken more quickly. Also because of the variation and incertitude of many parameters, management of such systems becomes much harder. [1]

As alternative to the monolithic approach, hierarchical approach is proposed to the supply chain management. This method allows us to divide the global problem to sub problems which are simpler to solve. These sub problems are linked each other within a hierarchical structure. Solving these problems one at a time, we may solve the entire problem in a lesser time. The inconvenience of this model however is we may not (and in most cases won't) obtain the optimal solution. But if the hierarchy is well constructed we will obtain an adequate and acceptable solution. [1][2]

2. Supply Chain Management

A supply chain is a network of installations that assures functions of supplying raw materials, transporting these raw materials, transforming these raw materials to parts then end product, distribution of end product to clients, and finally after sale service, recycling and scrap products at the end of life cycle. [1]

Supply chain is composed of an ensemble of processes and relations between different enterprises which business partners are aiming to optimize product displacement in the space and time with the goal of answering more efficiently to requirements of final consumer and principally at lowest delay and cost possible. In effect, today's enterprises does not suffice alone to answer the variable requirements of market provoked by competition. Thus, they reunite around common objectives connected at the same time to market and entire supply chain itself and it forms a complex and difficult to manage system which constitute of many plants for manufacturing many products, of many warehouses, of many distribution centers and of many clients. [1]

The fundamental characteristic which provokes the evident complexity of relations between the members of the supply chain is that the system precisely behaves as a chain. This signifies that each link has an impact on the remaining of the chain, positively and negatively. Thus, all ruptures of merchandises at a supplier will repeat until the final client; as all changes and incertitude of parameters such as the demand, lead times, capacity etc., provoke different responses at each link. In effect, if a part of the chain doesn't assure correctly its function, the end product can't be available at time, at the desired quality and cost. Then, the importance of a well supply chain management is no longer to demonstrate. [1]

The principal goal of enterprise constituting the supply chain (the suppliers, the plants, the distributors) is to be able to function each more efficiently remaining the member of the same chain. To achieve this, it should be planed, along all the chain, not only the demand of each plant, but also the production, scheduling, distribution, and transport at the stages of suppliers, plants and distributors to optimize the service level at the final consumer. [1]

This conducts supply chains, for example, to develop mathematical models to determine the production quantities, the time concerning the production until the delivery to final consumer, the quality level to be respected etc., taking into account the constraints of supplying, producing, stocking and distribution along the chain at the same time [3]. Since the supply chains are systems constituting of many variables and parameters having independent relations, a monolithic approach won't be appropriate, in term of efficiency, to model them. [1]

As indicated before, the hierarchical planning is a convenient model to plan and manage the incertitude and complexity inherited in the nature of supply chain and thus to minimize the costs and decrease response time to market. [1]

To better present the importance of the supply chain management, we give now, some examples of important decisions taken by the supply chain by a hierarchical way: [1][3][4]

1) Strategic Level

- The number, the location and the size of the plants and warehouses
- Capacity levels
- Technology and equipment acquisition
- Mode (truck, train, ship, etc) and network of transportation
- Method of supplying
- Supplier selection
- Outsourcing

- Standards of client services
- Divide of parts of market, objectives of profitability

2) Tactical Level

- Repartition of production capacity to product families
- Utilization rate for each plant and for entire network
- Workforce need (regular hours and extra hours)
- Affectation of plant/distribution centre couple
- Plans of transportation between plants
- Plans of inventory investment

3) Operational Level

- Scheduling at part production level (of end product)
- sequencing decisions of end products
- Short term inventory level balance and security stock level
- Quantity, time, and execution of command
- Scheduling of operations concerning warehouses
- Scheduling of workforce
- Scheduling of vehicles
- Selection of routing
- Transport batch size

2.1. Supply Chain Management: An Extension to Logistic

Supply chain management is a management mode appeared at 80's as an extension to logistic, as a result of the requirements of an environment becoming more and more competitive. Since the logistic does no longer suffice all alone to be competitive against market mutations, organizations are oriented to establish relations between themselves around common benefits against there opponents. Thus, the supply chain management concept is formed based on logistic. Since supply chain management is considered as a new generation of logistic, it is convenient to assimilate the notion of logistic before passing to concept of supply chain management. [1]

2.1.1. The Concept of Logistic

The concept of logistic appeared at 50's. The second industrial revolution, followed by the mass production and mass consumption has signaled the necessity of notion "mass distribution" [5]. In order to be able to respond to the market requirements and fortify the links between production and consumption, enterprises have started to lead on the notion of logistic. Until then, the concept was used by enterprises for a number of reasons such as the reduction of costs, increase of profits, acquiring or conservation of competitive advantage, diminution of fabrication cycle etc. Indeed, the mutations emerging in the market pushed the enterprises to change there viewpoint of logistic in order to survive. Since, there are many modifications in the domain of logistic utilization; the definition of concept is also modified in time.

One of the most recent definitions is the definition of CLM (Council of Logistics Management) which defines logistic as a "*the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements. Note that this definition includes inbound, outbound, internal and external movements, and return of materials for environmental purposes.* [6]".

Another definition is given by APICS (American Production and Inventory Control Society) as follows:

In an industrial context, the art and science of obtaining, producing, and distributing material and product in the proper place and in proper quantities. In a military sense (where it has greater usage), its meaning can also include the movement of personnel.

The logistic named at the beginning as "physical distribution", was composed of the domains of functioning: *transportation and warehousing*. But during twenty years it had to be modified and be extended to the ensemble of enterprise to become a tool capable of responding to the market changes. During this era, it has begun to influence the decisions of the enterprise concerning the organizational structure.

In origin, the role played by the logistic was centered on the functions of distribution which contributed to enterprises to deliver products in a less costly ways. However, it is now a competing "resource" that contains, also, other functions, than the one in the beginning, for example *purchase, supplying, inventory management, production planning and control, stocking end products, demand forecasting, after sale services*.

As remarked by Ross [7] during the last thirty years, the logistic has transformed from a function purely organizational to a fundamental element strategic of all the pioneer enterprises of fabrication and distribution. Nearly all enterprises actually accept that the logistic should be taken as an approach strategic but not operational.

2.1.2. Evolution of Logistic

Logistic has passed four important steps until reaching its final form. [8]

First Step: Decentralization of Logistic Functions (1950-1970)

In 50's and 60's, enterprises carried out a politic well focalized on the client and so the marketing was indispensable. In the research of increasing the sells, they consecrated enormous budgets to the publicities and to the production of new products. Evidently, this increased costs significantly. In order to decrease costs, the enterprises have chosen distribution function, because it constituted 10 30% of total costs and 40% of total stocks. [5]

This politic gave birth to notion of logistic. As indicated above, the logistic has been established, in a decentralized way, on two functions – transportation and warehousing functions – the first being under the responsibility of production and selling department, the second being under the control of finance and marketing department.

At the end of 60's, with the force of economical crisis, the optimization of costs have become a primordial measure. Moreover, mass production and scale economy concepts, forced the enterprises to find other solutions aiming to optimize costs. [7]

Second Step: Centralization of Logistic Functions (1970-1980)

The logistic centralization is provoked by the mass production as well as by informatics development and by the perpetual competition which have taken place on the entire world. To be specialized, the enterprises have reunited the transport and warehousing under the direction of a single department, thus they centralized physical distribution.

In previous steps, management approach was founded on the distribution costs while in this step importance is given to the total cost.

Third Step: Integrated Logistic (1980-1990)

When the competition has started to dominate the entire world, it has been noted that carrying out a politic based simply on total costs have become an approach all passive, in the new competitive environment.

In this regard, to decrease total costs and increase in the same time profits, a new tendency have appeared: to unify functioning of logistic and of management such as stock management, execution and command, planning and control of production, buying etc [7].

In the second step, to master, the costs and increase the competiveness at short term, transport and warehousing was centralized. In this step, the logistic is largely extended and activities like stock management, execution and command, planning and control of production, are added to the traditional activities of logistic. It is undeniable that integration of logistic functioning domains have augmented the level of competitiveness advantage of enterprises and it permits to enterprises to develop strategic plans concerning all the departments.

In the beginning of 80's, it has been noted that, competitive advantage will be more important, while not only several departments will be integrated but also firms on the same market. This is the idea that caused the apparition of a new approach logistic: Supply Chain Management.

Forth Step: Supply Chain Management (1990-…)

The supply chain management is an approach, emerged in 90's as an extension of third step, and connected to changes of logistic environment.

The supply chain defined by APICS as *the processes from the initial raw materials to the ultimate consumption of the finished product linking across supplier-user companies; and the functions within and outside a company that enable the value chain to make products and provide services to the customer*. [5]

This definition puts in relief three fundamental components of the supply chain: business partnership, material flow as well as information flow. [9]

The business partners are a series of supplier-client, that the management of relation is crucial to the success of the chain. The accent should be given to develop durable and profitable relations between business partners. The information flows, constitute all of the information exchanged in the chain, with its clients and suppliers. Information exchange between different services of and enterprise and different members of a supply chain is an important parameter. Indeed, if it does not posses an efficient network of information exchange with its suppliers and clients, the enterprise can not react to respond to requirement of the market. In order to maximize the efficiency of the ensemble of business partners of a supply chain, information supposing the material flow should be precise, timely and shared.

2.2. The Concept of Supply Chain Management

A supply chain is a series of suppliers and clients tied one to another where each client is the supplier of the previous member until attaining the final consumer. For this reason, the supply chain management is considered as a force unifying all the suppliers and clients and that permits them to function as an enterprise unique and thus to reduce total cost. Indeed, the unification emerge not only in the domain of logistic activities such as supplying, inventory management, transportation but also in the domains of marketing, development of product realized now by equips established by personnel of each member of the chain.

The coordination and planning of activities between the members are essentially for the supply chain management. Indeed, its objective is not only to improve the material and information flow flowing through all of the chain but also to construct an integrated system that permits to coordinate and plan the operations, even anticipate the requirements of the members of supply chain for protecting against effects of radical changes in the market. [10]

The supply chain management is distinguished from other concepts that aim to manage the procurement, the production and the distribution in two aspects:

The supply chain is a unique and independent process that the domains of functioning are not isolated one from other in terms of realization the goals and operations.

All the members of supply chain shares the interest tied to the success of the entire supply chain, in other terms, to respond to requirements of clients is the common objective of all the members.

Common objectives of enterprises constituting the supply chain are, for example, decreasing costs, market response time, increasing quality and service level, reduction of fabrication cycle, optimizing the stock, increase expertise etc.

However the most important inconvenience concerning supply chains is the difficulty to establish the confidence hence a strong cooperation between the members of the chain [11]. Because of the lack of confidence, the supply chains may not be constructed and those actually constructed may end, most of the time by failure. For example, with the fear that its know-how will be confined to rival, the enterprises producing technology never have intention to be a member of such a chain. But once the confidence is established, this permits to entire chain to reduce costs, response times to market and wasting, improve service levels and client satisfaction and consequently to enforce the competitive advantage.

By consequence, with the implementation of supply chain management, we aim in the first place, to reduce the operational costs realized previously in an independent way by each member and also deliver the product more rapidly. [7]

A supply chain can be very large consisted of many facilities, products and shipping routes. The number of variables in such a model can be overwhelming to be solved with monolithic approaches. This may be a very time consuming process. So in order to find a solution in a reasonable amount of time, other methods should be considered to solve such complex problems. As an alternative to the monolithic approach, we will use hierarchical approach in this study. The main advantage of this approach is the ability to solve complex problems in shorter times. But using hierarchical approach, we may not – and probably won't – find the optimal solution but a very close one [12]. In the next section, the philosophy and essential properties of hierarchical production planning method will be presented. Also some techniques, inconveniences, advantage and disadvantages of such a method will be discussed.

3. Hierarchical Production Planning

A production system is a group of resources constructed to transform the raw materials to end products. The production system cares about the efficiency of both information flow and product flow in the considered system in order to deliver the products where and when the demand appears, at required quantity and quality, and of course at a reasonable cost. The goal of the production management is to achieve an intended objective, using the production planning methods that contributes for example to:

- determine selling previsions,
- define the production plans by confrontation between the demand, the production capacities, supplies and hand craft,
- determine the needs of raw materials and parts required by the production plan etc.[1][8]

So, the production planning appears as an aspect essential to production systems in order to take efficient decisions which permit to satisfy better the client. Production planning consists of construction of production plans that results, in general, of mathematical models, so the goal is to help the decision using the possible objectives, the constraints of production system. By the way, the production decisions require choosing between a great number of alternatives with many contradictory alternatives under divers technological, financial and marketing constraints. These contradictory objectives of production planning may be of type:

- of minimization of total cost, of product cycle,
- of maximization of profit, of added value, and
- of optimization of the flexibility, of service level to client, of quality of capacity utilization.[1]

For mathematical models, minimizing the costs is the most widely utilized objective, because it is, for most enterprises, the essential policy. In the context of production system, the acceptable total cost as the objective may have components such as

- supplying cost,
- setup cost,
- stocking cost (of inventory),
- production cost,
- labor cost,
- extra working time cost,
- transportation cost etc.

depending to the model established.[1]

As indicated above, these objectives are generally contradictory. For example, minimization of production cost contradicts the maximization of capacity utilization. Using a single objective in the model is not obligatory. To deal with problems realistically, more than one objective may be determined (i.e. multi-objectives).[1]

While modeling, not only the objective(s) are introduced but the constraints are also introduced. These constraints consist of the attributes determining the comportment of system and puts limits to production activities. These are principally constraints:

- of financial and technological capacities,
- of equipment and hand craft capacities,
- production, supplying and transportation capacities,
- productivity ratio,
- demand and lead time incertitude,
- client service exigency.[1]

In general, solutions to complicated production problems are found thanks to production planning, but it is most of the time tiring and difficult. The production planning is a complex task considering the number variety of elements that characterize the production process and incertitude associated to the data to be used. [6]. These types of planning problems are mostly by the hierarchical production planning. Hierarchical production planning is an alternative method to be able to decrease incertitude by aggregation, simplify the complexity by dividing the decision structure to levels and so reduction of time required for the calculation to obtain the final solution that will help the decision taking.[1]

So, a hierarchical production planning system is a system that deals with the planning of a number of production systems, and also, of certain layers of decision making. The layers are relied between themselves by a decision flow which descends and by feedbacks of information on the state of the system that goes up in the hierarchy.[1]

In the literature of operations research, two different approaches are distinguished from the point of view of decision making: monolithic approach and hierarchical approach.[1][13][14][15].

3.1. Monolithic Approach to Planning

In the monolithic approach, the problem of decision making is described completely in a unique model. All of the variables of decision and the constraints appear in a detailed way in the model. The advantage of monolithic approach comes from the fact that le model can be established very simply. To achieve that it's sufficient to choose all of the variables of decision and to describe the relations that is convenient with the intended precision degree. [1]

Using such an approach, the optimal solution can be obtained, most of the time. By the way, decision making problems are presented at the form of mixed programming problems that becomes more difficult to solve as the number of variables are significant. In this case, adopting a hierarchical approach for the resolution of the complex problem appears as a convenient way to deal the difficulties

- reducing the complexity and dimension of the problem and so
- augmenting the easiness of the analyze, control and management of the entire system,
- increasing the number of models, and consequently, the number of planning period,
- eliminating effects of random cases and the variability of the aggregation,
- treating incertitude of the parameters and of the variables such as the demand, lead time, production time, the capacity to be used, reject ratio, selling or buying price etc.,
- intervening dynamism in the planning system by introducing rolling horizon notion,
- decreasing the calculations to obtain a decision.[1]

3.2. Hierarchical Approach to Planning

Hierarchical approach is proposed as an alternative to the approach monolithic. It is proposed by Hax and Meal, for the first time, to solve complex production planning problems. [1][16]

In the hierarchical approach, global problem is decomposed to simpler sub-problems. These sub-problems are hierarchically related to each other. All of these sub-problems require a planning and modeling that corresponds to a decision making layer. So, establishing a hierarchical production planning system means choosing a number of decision making layers, a model for each layer and finally a method to coordinate the decisions flow and information feedback between the layers. [1]

At the highest layer of the hierarchy, a general global model by which the strategy of the enterprise is determined is considered. At the highest layer, only aggregated entities are used. So the number of entities to be considered is reduced. Descending the hierarchy, the layers become more detailed. In this case the planning horizon is shortened compared to the decisions taken at higher layers. So, the term hierarchy signifies that a layer works is a workspace defined by a higher layer. [1]

The number of layers to be adopted depends according to decision maker and to the complexity of the considered system: as the complexity increases, the number of layers will increase too. Meanwhile, the finesse degree of information taken into consideration isn't the same: as the layer is lower, the information is finer and as the layer is higher, the information is more aggregate. [1][8]

Calculation time is shorter then monolithic approach. But, using such an approach, finding a sub-optimal solution is accepted at the beginning. The performance of the result or the proximity of the solution to the optimal will depend essentially according to the hierarchy choice. [1]

The most important gain of hierarchical approach is the simplicity because with such an approach, decisions are taken step by step in a successive fashion descending the established hierarchy. These decisions obtained by the hierarchical planning are taken in a way that aggregated decisions imposes constraints to the detailed decisions and in return detailed decisions returns a feedback to evaluate la quality of the aggregate decision. It is evident that taking efficient decisions requires an efficient modeling of the decision hierarchy. [1]

3.3. Hierarchical Structure of Decision System

All of the observable hierarchies contain a vertical arrangement of sub-systems. In this sense, the global system can be considered as a family of sub-systems in interaction. Each sub-system constitutes a decision layer. The success of the global system depends on the performance of all the decision layers. The performance of the global system can be measured with the feedback between the layers. At the highest layer of the hierarchy, the optimization of the global system's comportment is researched, on an important rolling horizon, compared to a chosen criterion. [1][15]

The hierarchisation of the production planning which has as a goal contribution to the decision making is based essentially on:

1. Hierarchical decomposition of decision system
2. Aggregation of data and decision variables
3. Coordination between decision layers (robustness and coherence) [1]

3.4. Hierarchical Decomposition of the Decision System

The hierarchisation of the decisions notion dates to 60s. Robert N. Antony is the first person to group decision into three classes. According to this classification decision relative to management are grouped in three categories:

1. Strategic planning
2. Management control
3. Operational control[16]

According to the conceptual cadre of Antony, hierarchical management goes from long term strategic planning to operational control, passing by mid term management control. This decomposition proposed by Antony presents a way of approaching to complex problems. Depending of studied problem each category can also be decomposed. That means the presentation of the categories is not unique. [16]

At 1970, a number of writers have renamed the decision categories: the second as tactical planning, and the third as operational planning [16]. These three planning classes, i.e. strategic, tactical and operational, are, today, becomes nearly anonymous terms by managers and academicians in all the planning management domains.

Essential idea of decision classification were to contribute to the design and planning of systems grouping them according there common characteristics such as time horizon concerning decision realization, considered layer detail, incertitude of decision taking etc. [1]

Antony has considered that all these three decision categories corresponds each to a planning layer which will be treated in details. These planning layers form between them a planning hierarchy and distinguish by detail level required, by the planning horizon length and by risks and cost of decision taken. [16]

3.4.1. Strategic Planning

Anthony defined the strategic planning as a decision process concerning organization objectives, objective changes, resources used to reach objectives and the politics of usage and disposition of resources. [16]

The strategic planning constitutes the highest layer in the decision making hierarchy and interests to the long term objectives of the organization. The goal of strategic planning is to situate the production system in its economical environment. Starting by the estimations of demand on planning horizon, the goal is adapting the capacity to the market tendency using of equipment investments, the buildings, personnel formation etc. The decisions taken in this layer are responsible of the capacity handling, determining increase ratio etc. [16]

Risk and incertitude levels are associated to the decisions increase and the detail level to be considered is decreased as the time interval increases. [16]

As planning horizon is measured by years, strategic decisions require major investments. [16]

3.4.2. Tactical Planning

This second class of the hierarchy is defined by Anthony as the process by which managers are assured that the resources are obtained and utilized efficiently and effectively to accomplish organization objectives. Attention is essentially on the process of utilization and resource allocation. [16]

Tactical planning has as objective, management of the production system on the planning horizon at mid-term. It is supposed that the needs of the market and system capacity are known as imposed by the strategic planning. On that layer repartition of the workload is considered taking into account quantitative and temporal capacities. Tactical planning generates final aggregate decisions as the inputs for lower layers. These decisions concern raw material supplying, material flow control along fabrication and distribution. [16]

Planning horizon is relatively shorter, mostly one year, so risk and incertitude levels are relatively low compared to the strategic planning. [16]

3.4.3. Operational Planning

Named first as operational control by Anthony, operational planning is defined as the process destined to assure the specific tasks are realized effectively and efficiently. [16]

Operational planning objective consists of scheduling, starting and managing activities of production resources in a fashion that works imposed by tactical layer are realized. Thanks to operational planning scheduling decisions and other operational decisions so called day-to-day are treated. [16]

Risk and incertitude levels of operational planning are the lowest between the three decision hierarchy layers. In contrast, detail level considered while planning is significant. [16]

Planning horizon is relatively short. Indeed, planning horizon is measured by days or weeks. This layer constitutes short term planning of organization. It should be remarked that decisions taken inefficiently at this layer, may collectively create, in the long term, supplementary costs and deviation to service level. So, decisions require a complete disaggregation of generated information and decisions taken at higher layers in a fashion that they are coherent with the procedure followed by the operational activities. [16]

It may be said, from a global view point, and taking into account what have been said before about the three categories of planning:

- strategic planning corresponds to capital investments and physical installation,
- tactical planning corresponds to aggregated production planning,
- operational planning corresponds to detailed (or disaggregate) production planning. [16]

These three categories can't be in isolation because they interact strongly between themselves. In the context of a hierarchical planning system, that will be treated more detailed later, the decisions taken superior and inferior layers must be bound by an effective manner, in such a way that decisions superior provide a constraints to inferiors and in the other part inferior decisions provide a feedback required for the evaluation of the quality of the aggregate decision taken to the superior layer. [16]

After treating the hierarchical decomposition of decisions, it is now convenient to introduce aggregation and disaggregation principles of decision which are indispensable for hierarchical planning. [16]

3.5. Aggregation/Disaggregation of Decisions

Aggregation principle may be defined as an abstraction form thanks to whom an ensemble of data may be replaced by another less important ensemble of data of same type [17]. This principle permits to reduce number of information to be treated, at a layer given in the planning problem [15].

Aggregation concept seams interesting to simplify the modeling of problems having complex models and being hard because of considerable number of parameters and variables. Aggregation may also be employed with the goal of reducing calculation quantity and information variance. [1]

Aggregation may be applied to many types of intervening actors in the planning process [8] such as time, products, production methods etc.

Time aggregation consists of discreting the time, which is a continuous length and of considering as a succession of intervals of time called periods. This principle is applied implicitly in modeling of many problems. The length of a period depends of aggregation layer where the problem is played. At strategic decisions layer, which are charged to manage long term production, the period is measured by months for example, but for short term management that the role is scheduling on the machines the period is measured by hours or minutes. [8]

Product aggregation consists of regrouping the products to classes of products with the goal of reducing the number of parameters to manipulate. In general, products having similar characteristics are compiled into the same class, for example, seasonal comportment, production rate, production costs, inventory and setup. [8]

Production method aggregation comports two types of aggregation logic: aggregation to blocks and aggregation to lines. Aggregation to blocks consists to regroup machines having similar characteristics, for example effecting the same operations, but eventually with differences of execution time, setup time, and technical constraints. Aggregation to lines consider as a single machine, certain number of machines which are generally found under the same order in the routing of products. [8]

Aggregation may also be classified, in more details, as

- Temporal aggregation
- Special aggregation
- Aggregation tied to product structure
- Aggregation tied to capacity and resources
- Aggregation tied to demand
- Aggregation tied to product costs
- Aggregation tied to production times

To illustrate, it is convenient to give en example of modeling at aggregate and disaggregate levels where aggregation is realized on products. Let's consider two products manufactured in the same unit of production. The demand is supposed continuous. Lets $d_1(t)$ and $d_2(t)$ the demands of product 1 and 2 respectively at period t. Production times are equal. Total production capacity may vary from period to period and is denoted by $C(t)$. Two types of costs exist: inventory cost and manufacturing cost. [1]

Lets $x_1(t)$ and $x_2(t)$ be quantity of production of products 1 and 2 respectively in the period t. The fabrication cost in the period t depends only of $x_1(t) + x_2(t)$ and is defined as $f(x_1(t) + x_2(t))$. Lets $I_1(t)$ and $I_2(t)$ be quantity of inventory for products 1 and 2 respectively at the end of period t. Inventory cost at the period is defined as $g(I_i(t))$. Initial inventories are zero ($I_1(0)= I_2(0)=0$).

The objective is to minimize total cost for T next periods. The problem may be represented at disaggregated level as:

$$\min \sum_{t=1}^{T} \{[g(I_1(t)) + g(I_2(t))] + f(x_1(t) + x_1(t))\} \tag{3.1}$$

subject to

$$I_1(t+1) = I_1(t) + x_1(t+1) - d_1(t+1), \quad t = 0,1,\ldots,T-1 \tag{3.2}$$

$$I_2(t+1) = I_2(t) + x_2(t+1) - d_2(t+1), \quad t = 0,1,\ldots,T-1 \tag{3.3}$$

$$I_1(0) = I_2(0) = 0 \tag{3.4}$$

$$x_1(t) + x_2(t) \le C(t), \quad t = 0,1,\ldots,T \tag{3.5}$$

$$x_1(t) \ge 0, x_2(t) \ge 0, \quad t = 0,1,\ldots,T \tag{3.6}$$

Contrarily, the model at aggregated level is at the form

$$\min \sum_{t=1}^{T} \{ g(I(t)) + f(x(t)) \} \tag{3.7}$$

subject to

$$I(t+1) = I(t) + x(t+1) - d_1(t+1) - d_2(t+1), \quad t = 0,1,\ldots,T-1 \tag{3.8}$$

$$I(0) = 0 \tag{3.9}$$

$$x(t) \geq 0, \quad t = 0,1,\ldots,T \tag{3.10}$$

Detailed model that constitutes of *T* periods may be solved resolving first the aggregate model then distributing total production quantity in a way that inventories are equal. At this distribution, it isn’t necessary to look beyond first period. Planning problem is divided into two: an aggregate problem over *T* periods and a detailed problem over one period. [18]

According to Wijngaard, aggregated level depends of the organization flexibility and of instability or incertitude of the environment. For example, the possibility to change easily production from one product to another permits to aggregate the products. The mobility between capacities permits the possibility to aggregate the capacities. By the way, for both cases, the variability of demand puts restrictions on possibility of aggregation. [18]

Generally speaking, incertitude inherited in the nature of planning process limits implementation of aggregate results for next periods of planning. As the models used for the industrial production planning are, most of the time, deterministic models, rolling horizon concept is generally used to reduce effects of incertitude to obtain realistic solutions. [1]

Rolling horizon indicate that hierarchical model is solved for a horizon of given time. By the way, the part of the solution concerning only near future is executed. The model is the rolled to the point of decision more close. Before integrating to the decision system, the information is adjusted and the model is solved again. One more time, the first part of the solution is executed and so on. [19]

Briefly, aggregate and disaggregate plans are revised periodically at a rolling horizon as better previsions are obtained. Usage of a rolling horizon at the process of planning permits to ease integration of perturbations in the system. So existence of such a concept puts in place the comportment of system in real time. [1]

Aggregation and disaggregation principle may also be serving to present models of different detail levels, at different levels of decision makers. The models reduced to intermediary of aggregation, guard generally the same structure as the original model and require less calculation. So, a standard strategy to solve complex production planning problems is to proceed hierarchically to several levels where inferior levels comports information imposed by aggregate levels of superior levels. Such a principle wouldn't have any meaning if we were not capable of detailing (disaggregating) aggregate quantities at superior levels and if we don't obtain agreeable solutions, i.e. close to the optimal solution, by hierarchical approach. At this state, the coherence and robustness between different levels appears as essential objectives to have an aggregation disaggregation process efficient. [1]

3.6. Robustness and Coherence

The sequential solution of a sub-model hierarchy may conduct to sub-optimality, incoherence, infeasibility if sub models aren't coordinated effectively. As in practice the objectives of each decision level are generally contradictory, this brings the hierarchical system to deterioration as an integrative solution is not derived. In other terms, it is not sufficient to have aggregate and disaggregate planning procedures defined completely separately, but they should be combined. [19]

These coordination mechanisms should assure the coherence and deliver solutions close to the optimal. This constitutes the essential problem of a hierarchical planning system. [19]

To assure a satisfactory functioning of structures merged on aggregation disaggregation mechanisms, it is indispensable to study interactions between successive decision levels. Analyze of these interactions conduct to degage two fundamental concepts: The robustness of aggregation and the coherence of disaggregation. [14]

The robustness of an aggregated decision (taken by superior level) assures the existence at inferior level, of a feasible detailed solution obtained by disaggregation. And inversely, a detailed solution (taken by inferior level) is said coherent with superior level when it is compatible with the ensemble of aggregate decisions. [20]

An aggregate plan is said to be feasible if it can be disaggregated to a detailed plan [21]. At literature, when the case is determinist the term “feasible” is used instead of term “robust” which is first imposed by Lasserre et Mercé in 1990.[22]

For a given initial state, the aggregate plan is robust if and only if a feasible disaggregation exists. Such a plan is said to be coherent. [21]

The disaggregation of aggregate plans is generally executed in a context of rolling horizon which signifies that a detailed plan for the first period of planning horizon should be defined. The problem gets back to disaggregation the first period of aggregate production assuring the coherence with the entire aggregate plan. This situation brings us to another definition:

An aggregate plan being robust, the disaggregation of first period, of aggregate production is coherent if it,

- satisfies detailed information for the first period
- retains the robustness (feasibility) of aggregate plan for next periods (from 2 to T) [22]

Infeasibility sources are generally because of the stochastic nature of processes (demands, ruptures, failure, reject ratio, absences etc.). These infeasibilities may be evaded by introduction of the flexibility notion which is a standard procedure used in practice to reinforce the feasibility [19]. In theory, conditions required and sufficient relative to the coherence and robustness are used. [1]

To detail, we will demonstrate using a simple example from production domain, how these infeasibility appears and we will describe a method to eliminate infeasibility. [15]

The problem consist one type of product (i=1), three items (k=1,2,3), a planning horizon divided in two periods (t=1,2).

Aggregation constraints are:

$$S_0 + X_1 - S_1 = D_1 \tag{3.11}$$

$$S_1 + X_2 - S_2 = D_2 \tag{3.12}$$

Non-negativity constraints

Detailed level constraints are:

$$s_{k,0} + x_{k,1} - s_{k,1} = d_{k,1}, \quad k = 1,2,3 \tag{3.13}$$

$$s_{k,1} + x_{k,2} - s_{k,2} = d_{k,2}, \quad k = 1,2,3 \tag{3.14}$$

Non negativity constraints

Feasibility constraints imply that these two constraints are satisfied and that equality stays true:

$$\sum_{k=1}^{3} x_{k,t} = X_t, \quad t = 1,2 \tag{3.15}$$

Lets consider demands and initial stocks of table 3.1

Table 3.1 Demand and Initial Stock

	Initial Stock	Demands	
Items		for t=1	For t=2
k=1	$S_{1,0}$=6	$d_{1,1}$=2	$d_{1,2}$=2
k=2	$S_{2,0}$=2	$d_{2,1}$=3	$d_{2,2}$=2
k=3	$S_{3,0}$=1	$d_{3,1}$=6	$d_{3,3}$=2
Total	S_0=9	D_1=11	D_2=6

It can easily be verified that solution X_1=6, X_2=2, S_1=4, S_2=0 is feasible for aggregate level problem but doesn't have a feasible disaggregation. The reason of infeasibility is that the aggregate model ignores the fact that second and third items can't utilize stock of first item.

This infeasibility can be avoided using effective demands. If initial stock for item k is not null, we subtract it then, from the demand of first period to obtain effective demand of that period. If initial stock is greater that the demand of first period, the same adjustment procedure is repeated until all of the stock is used. The effective demands of example are given in the table 3.2.

Table 3.2 Initial Stock and Effective Demands

Items	Initial Stock	Effective Demands for t=1	Effective Demands For t=2
k=1	$s_{1,0}$=0	$d_{1,1}$=0	$d_{1,2}$=0
k=2	$S_{2,0}$=0	$d_{2,1}$=1	$d_{2,2}$=2
k=3	$S_{3,0}$=0	$d_{3,1}$=5	$d_{3,3}$=2
Total	S_0=0	D_1=6	D_2=4

If we work with effective demands, whatever the feasible solution for the aggregate model is, it will give a feasible solution for detailed model.

Erchler, Fontan and Mercé [21] treated to improve the procedure developed by Hax and examined by Bitran. A decision center that should distribute aggregate production between different products satisfying demands is considered. In order to permit a better reactivity to interfering variations of production, the authors applies a dynamic decision making procedure: The production plan for T periods is searched where

$$x_t = (x_{1t}, x_{2t}, \ldots, x_{nt}) \quad (3.16)$$

represents the production at period t, should satisfy the demands

$$s_t = s_{t-1} + x_t - d_t, \quad t = 1, \ldots, T \quad (3.17)$$

$$s_t \geq 0, \quad t = 1, \ldots, T \quad (3.18)$$

$$x_t \geq 0, \quad t = 1, \ldots, T \quad (3.19)$$

and respect fixed aggregate quantities by plan X

$$\sum_{k=1}^{n} x_{k,t} = X_t, \quad t = 1,\ldots,T \;\; x_t \geq 0, \quad t = 1,\ldots,T \tag{3.20}$$

The decision x chosen is said to be admissible for s_0, X and d, if it satisfies the constraints (3.17),(3.18),(3.19),(3.20), for t=τ. Such a decision doesn't assure the existence of an admissible plan on the rest of horizon. Supplementary constraints should then be defined in order to make this decision "coherent" with aggregate plan.

We continue with the same problem taking into account only the first period. So, a decision x_1 non negative is feasible if:

$$s_0 + x_1 \geq d_1 \tag{3.21}$$

$$\sum_{k=1}^{n} x_{k,1} = X_1 \tag{3.22}$$

Lets aggregate plan X_1=8; X_2=3 which has at least one admissible detailed plan (for example: x_1=(1,2,5) and x_2=(0,1,2))

Lets consider now the decision x_1=(2,1,5). Although it is feasible, it is not coherent with the fixed aggregate plan. In effect, considering detailed stock obtained (s_1=(6,0,0)) and aggregate production X_2=3, it isn't possible to satisfy the demand in period 2 for products 2 and 3 in the same time. So, a decision x_1 is coherent having s_0, X, d:

- if it is feasible
- if exist an admissible detailed plan exist (x_t, t=2,…T) for

$$s_1 = s_0 + x_1 - d_1 \tag{3.23}$$

$$X_t, t = 2,\ldots,T \tag{3.24}$$

$$d_t, t = 2,\ldots,T \tag{3.25}$$

An aggregate plan is robust if it assures the existence at least one solution at detailed decisional level. An aggregate plan X is said to be admissible aggregate if it assures the satisfaction of aggregate demands, i.e. if:

$$\sum_{j=1}^{t} X_j \geq \sum_{j=1}^{t} D_j - S_0, \quad t = 1,\ldots,T \text{ with } X_j \geq 0, \quad j = 1,\ldots,T \tag{3.26}$$

An aggregate plan X is said to be robust if it can be disaggregated to an admissible detailed plan. So the relations (3.26) lead to the conditions of aggregate admissibility:

$$X_1 \geq 2 \text{ and } X_1 + X_2 \geq 8 \tag{3.27}$$

The plan X_1=3; X_2=5 is then aggregate admissible. However taking into account detailed stocks s_0=(6,2,1) and detailed demand d_1=(2,3,6), it isn't possible to find a detailed plan admissible. That means this aggregate plan is not robust.

Then, the authors [21] establish the necessary and sufficient conditions of robustness utilizing the study of Gabbay [23]. In conclusion, an aggregate plan is robust if and only if,

$$\sum_{j=1}^{t} X_j \geq \sum_{k=1}^{n} \max\left(0, \sum_{j=1}^{t} d_{kj} - s_{k0}\right), \quad t = 1,\ldots,T \tag{3.28}$$

This condition expresses the fact that the aggregate production should permit to respond to detailed demands non-satisfied by initial detailed stock. By consequence, according to example, a plan is then robust if

$$X_1 \geq 6 \text{ and } X_1 + X_2 \geq 10 \tag{3.29}$$

Integrating to the hierarchical system the necessary and sufficient conditions tied to the coherence, we can improve the disaggregation procedure without modifying the structure of studied problem [21]. And also, employing available information to impose in the aggregate plan of robustness conditions, we can assure the existence of feasible disaggregation for each planning period [24]. The necessary and sufficient conditions of integrated robustness in the aggregate plan permits easiness in term of execution of plan [22].

In the context of this study, we will present you a literature review. In this review, we have focused on the usage of hierarchical techniques on the supply chain management. Several articles on the subject and there short abstracts will be presented in the next section.

4. Literature Review

For years, researchers and practitioners have primarily investigated the various processes within manufacturing supply chains individually. Recently, however, there has been increasing attention placed on the performance, design, and analysis of the supply chain as a whole. [25]. It exist a large spectrum of research areas in the supply chain management but in this review, we are only interested on essential idea consisting modeling a supply chain in an integrated and hierarchical way.

Beamon [25] have mainly provided a focused review of literature in multi-stage supply chain modeling and defined a research agenda for future research in this area.

Petrovic, Roy and Petrovic [26][27] describes fuzzy modeling and simulation of a supply chain in an uncertain environment, as the first step in developing a decision support system. A supply chain is viewed as a series of facilities that performs the procurement of raw material, its transformation to intermediate and end-products, and distribution and selling of the end-products to customers. All the facilities in the supply chain are coupled and interrelated in a way that decisions made at one facility affect the performance of others. Supply chain fuzzy models and a simulator cover operational supply chain control. The objective is to determine the stock levels and order quantities for each inventory in a supply chain during a finite time horizon to obtain an acceptable delivery performance at a reasonable total cost for the whole supply chain. Two sources of uncertainty inherent in the external environment in which the supply chain operates were identified and modeled: customer demand and external supply of raw material. They were interpreted and represented by fuzzy sets. In addition to the fuzzy supply chain models, a special supply chain simulator was developed. The supply chain simulator provides a dynamic view of the supply chain and assesses the impact of decisions recommended by the supply chain fuzzy models on supply chain performance.

Li, O'Brien [28] have focused on improving supply chain efficiency and effectiveness under four criteria, profit, lead time performance, delivery promptness and waste elimination, instead of the cost alone. The model established in the paper analyses the supply chain performance at two levels, the chain level and the operations level. At the chain level, objectives associated with the criteria are set for each supply chain stage so that the supply chain performance can meet the customer service target and the best supply chain management strategy is selected. At the operations level, manufacturing and logistics activities are optimized under the given targets. This paper analyses the supply chain performance in a hierarchical way so that benefits of the whole supply chain and its individual companies can be balanced.

Özdamar and Yazgaç [29] developed a production-distribution model involving production and transportation decisions in a central factory and its warehouses. The model is based on the operating system of a multi-national company producing detergents in a central factory from which products are distributed to geographically distant warehouses. The overall system costs are optimized considering factory and warehouse inventory costs and transportation costs. Constraints include production capacity, inventory balance and fleet size integrity. Here, a hierarchical approach is adopted in order to make use of medium range aggregate information, as well as to satisfy weekly fluctuating demand with an optimal fleet size. Thus, a model which involves an aggregation of products, demand, capacity, and time periods is solved. In the next planning phase, the aggregate decisions are disaggregated into refined decisions in terms of time periods, product families, inventory and distribution quantities related to warehouses. Consistency between the aggregate and disaggregation models is obtained by imposing additional constraints on the disaggregation model. Infeasibilities in the disaggregated solution are resolved through an iterative constraint relaxation scheme which is activated in response to infeasible solutions pertaining to different causes. Here, they investigate the robustness of the hierarchical model in terms of infeasibilities occurring due to the highly fluctuating nature of demand in the refined time periods and also due to the aggregation process itself.

Sabria and Beamon [30] have developed, an integrated multi-objective supply chain model for use in simultaneous strategic and operational supply chain planning. Multi-objective decision analysis is adopted to allow use of a performance measurement system that includes cost, customer service levels (fill rates), and flexibility (volume or delivery). This measurement system provides more comprehensive measurement of supply chain system performance than do traditional, single-measure approaches. Moreover, this model incorporates production, delivery, and demand uncertainty, and provides a multi-objective performance vector for the entire supply chain network. The model developed here will aid in the: (1) design of efficient, effective, and flexible supply chain systems and (2) evaluation of competing supply chain networks.

Goetschalckx, Carlos and Dogan [31], focused to demonstrate the savings potential generated by the integration of the design of strategic global supply chain networks with the determination of tactical production–distribution allocations and transfer prices. The logistics systems design problem is defined as follows: given a set of potential suppliers, potential manufacturing facilities, and distribution centers with multiple possible configurations, and customers with deterministic demands, determine the configuration of the production–distribution system and the transfer prices between various subsidiaries of the corporation such that seasonal customer demands and service requirements are met and the after tax profit of the corporation is maximized. The after tax profit is the difference between the sales revenue minus the total system cost and taxes. The total cost is defined as the sum of supply, production, transportation, inventory, and facility costs. Two models and their associated solution algorithms will be introduced. The savings opportunities created by designing the system with a methodology that integrates strategic and tactical decisions rather than in a hierarchical fashion are demonstrated with two case studies.

Schneeweiss[32] gives an overview over the broad area of distributed decision making. In achieving a systematic procedure a general framework is developed that allows describing the numerous approaches in distributed decision making in a unified way. Focusing on application areas the paper is not only considering various fields in the management sciences, like hierarchical production planning, supply chain management, or managerial accounting, but is regarding other disciplines as well. Particularly, economics and computer sciences are investigated as to their specific contributions to distributed decision making. It turns out that each field and discipline elaborate different aspects of distributed decision making which particularly for operational research could be used to solve concrete highly involved distributed decision making problems.

Schneeweiss and Zimmer [33], analyzed operational coordination mechanisms between a producer and a supplier within a supply chain having private local information. For a make to order production setting the coordination is achieved through the combined use of a task-oriented and a control-oriented type of instrument. The task-oriented instrument describes the producer's procurement policy for components whereas the control-oriented instrument is made up by penalty costs for non-correct delivery. In using both of these instruments various coordination schemes are employed in making use of the theory of hierarchical planning. Though it is assumed that producer and supplier possess some private information they are not taken to behave antagonistically. The question, which information should be disclosed, is of central importance for the overall performance of the supply chain and is the main focus of an extensive quantitative analysis which finally is used to give recommendations for the design of a supply contract.

Icen [1], have adopted the hierarchical production planning approach to the supply chain management. She considered a supply chain constituting several stages and facilities. She considered a single type of product in each stage. Every facility at each stage produced that single type of product.

Hurtubise, Olivier, Gharbi [34] introduce a new way to manage the supply chain. The proposed solution reduces the problem's complexity using a two-stage hierarchical production planning method and is applicable to realistic transportation optimization problems. The approach is based on planning and operations scheduling models, and is designed to minimize travel and production costs within a flexible organizational network. In the aggregate planning phase, a mathematical model involving an aggregation of products, demand and time periods are solved. It is at this initial stage that the size of the problem is reduced and its output is used as input to the detailed phase in order to improve resolution time. The second stage produces a detailed schedule. It is shown that the proposed approach generates good and feasible solutions to practical problems within a reasonable computational time.

Blackhurst, Wu and Craighead [35] presented a methodology, extending the concept of basic Petri Nets, to discover supply chain conflict before they occur and cause detrimental effects to system performance. The approach involves linking hierarchical levels of the supply chain system and detecting conflicts occurring when the single entities, each optimized for it own operations, are combined together in a supply chain. These conflicts are not obvious or intuitive in examining the single entities of the supply chain, but when integrated the conflicts are discovered by the methodology. They applied the proposed methodology on a real-world supply chain to illustrate the validity of the tool. Although, further research is needed to fully explore this method of conflict detection, we believe that this research does indeed provide some much needed insight into the daunting task of conflict discovery and therefore proactive handling of these potentially negative occurrences in the supply chain.

Xie, Petrovic and Burnham [36], presented a new hierarchical, two-level approach to inventory management and control in supply chains. A supply chain is viewed as a large-scale system that consists of production and inventory units, organized in a serial structure. It is supposed that the supply chain operates under uncertainty in customer demand, which is described by imprecise terms and modeled by fuzzy sets. Overall supply chain inventories control is achieved at two levels. First, a supply chain problem is decomposed into a number of sub problems related to its constituent parts, which form a follower's level. Each follower is optimized independently according to its local objective. In order to improve overall supply chain performance, a leader level coordinates supply chain inventories control by modifying the optimization sub problems at the follower's level. This process is repeated iteratively until a satisfactory overall supply chain performance is achieved.

As we have seen several works done on the usage of hierarchical techniques on supply chain management, we will now present the model that we have constructed. In this model, we have aimed to construct a flexible and simple to solve model. The model can easily be extended and modified according to specific needs. In the next section, you'll find the detailed explanation of the model. We have also provided a hypothetical example to help better understand the underlying mechanism of the model.

5. Supply Chain Model

In this section we will elaborate a supply chain using hierarchical production planning model. Our model consists of N stages. The output of each stage is the input of next stage. The production starts at stage N and ends at stage 1. The final product is shipped from stage 1 to the costumers. Each stage has a lead time. After the production order the products arrives to the next stage in l (lead time) periods. Lead time for any stage n is denoted as l_n.

Each stage consists of several facilities which accept as raw material products from previous stage and sends finished products to the next stage. Stage N which is the beginning of the supply chain doesn't require raw material and stage 1 which is the end of the supply chain ships to the costumers. The number of facilities at stage n is denoted as J_n.

Each facility produces several types of products. The facilities of the same stage produce the same products. These products are send to the next stage of the supply chain as raw materials. The number of product types at stage n is denoted as I_n.

Producing a product at a stage requires several types of raw materials from previous stage. The number of products i_{n+1} required to produce one unit of product i_n at stage n is denoted as $f_{ni_ni_{n+1}}$.

Our model is illustrated in the figure 5.1.

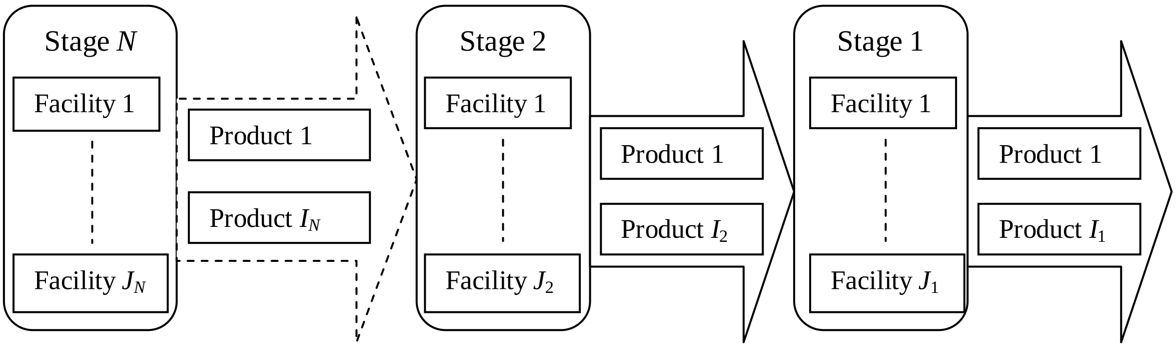

Figure 5.1 Supply Chain Product Flow

Note that facilities in different stages numbered with the same number are in fact different facilities. The same also applies for the product numbering.

In this model we consider mainly three costs namely production, inventory and shipping costs. So our objective is to minimize the total of these three costs.

We will use hierarchical production planning for this problem. As facilities under the same stage produce the same products and as products have similar production times and methods, it is convenient to aggregate them. In aggregate model we will find aggregate production at each stage. In disaggregation model we will distribute the productions to the facilities.

Also, with each model we will supply an example to better illustrate the model constructed. This example is hypothetical but very realistic and consists of three stages. In real life the model would be much more big and complex but for the sake of simplicity we have chosen a simple example. Also we have been able to solve the problem using a software on computer.

We consider the hypothetical supply chain with three stages as illustrated in figure 5.2.

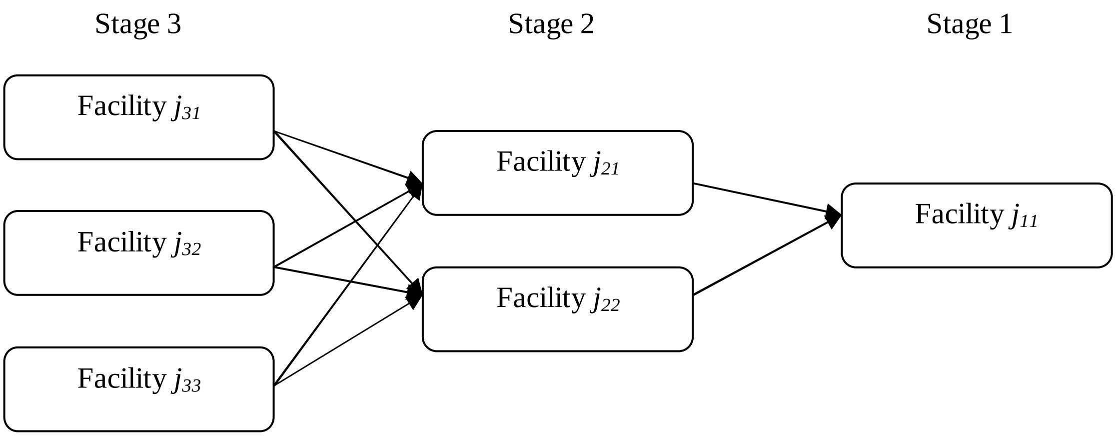

Figure 5.2 Supply Chain Structure and Relations

The arrows symbolize material flow between facilities. Many types of products will flow between facilities. As the products have similar characteristics and production methods, facilities within the same stage can produce the same products. Each facility has different capacity.

5.1. Aggregation

5.1.1. Model

As stated before we will aggregate facilities under the same stage. So as a variable we won't have facilities. Each stage will be treated as a unified production facility. Our objective will be to minimize production and inventory costs for aggregate model. The model can be described in details as follows:

Notation:

Indexes:

n: stage level index

i_n: product family index

t: time index

Parameters:

$Cprod_{ni_nt}$: aggregate production cost at stage n, of product i_n, at period t

$Cinv_{ni_nt}$: aggregate inventory cost at stage n, of product i_n, at period t

C_n: production capacity at stage n

$f_{ni_ni_{n+1}}$: number of product i_{n+1} required to produce one unit of i_n at stage n

l_n: lead time at stage n

Decision Variables:

X_{ni_nt}: aggregate number of units of product i_n to be produced at stage n at period t

I_{ni_nt}: aggregate number of units of product i_n to stock at stage n at period t

D_{ni_nt}: aggregate number of units of product i_n to be demanded at stage n at period t

The planning period of each stage starts at T_n+1 where T_n is defined as:

$$T_n = \sum_{s=n+1}^{N} l_s$$

where

l_s is the lead-time of stage s.

So for the last period (N) T_N=0 so the planning starts at period $T_N + 1 = 1$.

And the planning period for stage N-1 starts at period $T_{N-1} + 1 = l_N + 1$.

And so on, finally for the first stage planning starts at period $T_1 + 1 = l_1 + l_2 + \ldots + l_N + 1$.

The objective function can be written as:

$$\min \sum_{n=1}^{N} \sum_{i_n=1}^{I_n} \sum_{t=T_n+1}^{T+T_n+1} Cprod_{ni_nt} X_{ni_nt} + \sum_{n=1}^{N} \sum_{i_n=1}^{I_n} \sum_{t=T_n+1}^{T+T_n+1} Cinv_{ni_nt} I_{ni_nt} \tag{5.1}$$

The objective function is composed of two parts. The first part is the production costs. Production cost is calculated by summing number of product produced of each unit type (i_n), at each stage (n), every period (t).The same also applies to the inventory costs which consists the second part of the objective function.

subject to,

$$I_{ni_nt-1} + X_{ni_nt} - I_{ni_nt} = D_{ni_nt} \quad n = 1\ldots N, \;\; i_n = 1\ldots I_n, \;\; t = T_n + 1\ldots T + T_n + 1 \qquad (5.2)$$

Constraint (5.2) simply maintains the balance between productions, inventories and demands at the considered period. We add production of period *t* to inventory of period *t*-1 thus we obtain available stock level. Subtracting inventory at stage *t* we obtain amount shipped which should be equal to demand at period *t*. This constraint should apply to all products at all stages in every period.

$$D_{n+1 i_{n+1} t-l_{n+1}} = \sum_{i_n=1}^{I_n} f_{ni_ni_{n+1}} X_{ni_nt}, \quad n = 1\ldots N-1, \;\; i_{n+1} = 1\ldots I_{n+1}, \;\; t = T_n + 1\ldots T + T_n + 1 \qquad (5.3)$$

Constraint (5.3) assures that the raw material required for stage *n* is supplied by stage *n*+1 (lower stage of stage *n*). The required raw material at period *t* for stage *n* is calculated by multiplying the production amount by the *f* coefficient and summing it for all products of stage *n*. So total product required is calculated. This value is the demand for the lower stage. Note that this demand should be satisfied in lead time advance of the lower stage (*n*+1) so the demand calculated is for period $t - l_{n+1}$.

$$\sum_{i_n=1}^{I_n} X_{ni_nt} \le C_n, \quad n = 1\ldots N, \quad t = T_n + 1\ldots T + T_n + 1 \qquad (5.4)$$

Constraint (5.4) is the capacity constraint.

$$\sum_{\tau=1}^{t} X_{ni_n\tau} = \sum_{\tau=1}^{t} D_{ni_n\tau}, \quad n = 1\ldots N-1, \;\; i_{n+1} = 1\ldots I_{n+1}, \;\; t = T_n + 1\ldots T + T_n + 1 \qquad (5.5)$$

Constraint (5.5) is the feasibility condition of an aggregate plan as suggested by Axsäter. [21][37]

5.1.2. Example

To ease the model we aggregate facilities under the same stage as a family. So for the aggregate model we will consider the following model.

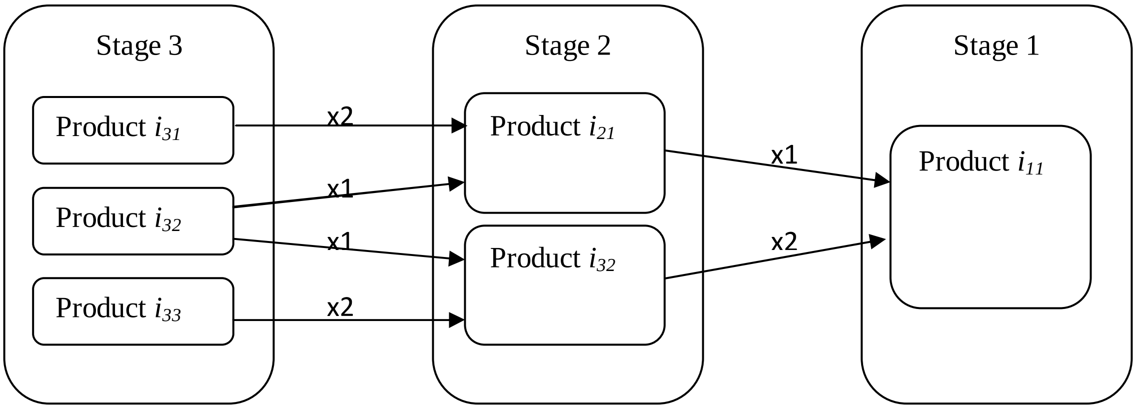

Figure 5.3 Raw Material Requirements

In diagram 5.3, the arrows show number of material to produce a product. In this model we don't take into account facilities. We are considering whole stage as a single facility. In disaggregation model productions will be distributed between facilities.

The planning starts at period 1. To obtain demand to stage 3 we should know production of stage 2. Considering the lead time of 1 period at stage 3, we should start planning for period 2 at time 1+1(lead time+1)=2. And as well for stage 1 planning will start at period 2+2 as lead time at stage 2 is equal to 2 periods. We will consider a planning horizon of 4 periods. These data are summarized at the following table.

Table 5.1 Planning Horizon

Stage (n)	3	2	1
Lead Time (l_n)	1	2	-
Planning Periods (T_n+1) - (T_n+1)+3	1-4	2-5	4-7

In this model, we are trying to minimize certain costs. The costs we'll consider in this model are production and inventory costs. These costs are summarized at following table.

Table 5.2 Production Costs

Production Costs	Product 1	Product 2	Product 3
Stage 1	50	-	-
Stage 2	40	30	-
Stage 3	30	20	20

Table 5.3 Inventory Costs

Inventory Costs	Product 1	Product 2	Product 3
Stage 1	5	-	-
Stage 2	3	4	-
Stage 3	3	5	4

Also we should consider production capacities. Capacities are aggregated for each stage.

Table 5.4 Production Capacities

Stage	Capacity
1	100
2	350
3	1000

The lead times are

Table 5.5 Lead Times

Stage	Lead Time
1	1
2	1
3	2

The followings are demands to the stage 0 which is outgoing of our supply chain. We should provide these in specified times.

Table 5.6 Initial Demands

Period	Demand
5	80
6	90
7	110
8	105

Applying these data to the aggregate part of our hierarchical model, we obtain the following results.

Table 5.7 Obtained Demands

		Period						
Stage	Facility	1	2	3	4	5	6	7
3	1	324	104	176	166			
	2	333	333	333	156			
	3	342	562	490	146			
2	1		85	100	100	100		
	2		170	200	200	200		
1	1				80	90	110	105

Table 5.8 Obtained Productions

		Period						
Stage	Facility	1	2	3	4	5	6	7
3	1	325	103	176	166			
	2	333	333	333	156			
	3	342	562	490	146			
2	1		162	52	88	83		
	2		171	281	245	73		
1	1				85	100	100	100

Other information obtained is not critical for our disaggregation, so we do not give them here. As we are interested with detailed production quantities at each facility we have to disaggregate these results. For example at stage 3 we should produce 325 items of product 1 at period 1 but we don't know which facilities will produce how many of this item. In the disaggregation we will look for that information.

We pass these results as constraints to the disaggregation model. The disaggregation model will take care of distribution of production between facilities.

5.2. Disaggregation

5.2.1. Model

As we obtain aggregate production at each stage we will distribute it now through the facilities. Doing that, we should remain within the limits determined by the aggregate function. In this model we won't consider inventory costs as we are only interested to the first period production of each stage. We will consider production and shipping costs by the way.

The fact that we are only interested for the first period of each stage decreases significantly the number of variables we have to deal with. The downside is we should maintain feasibility for the rest of the planning horizon. To do so we integrate feasibility constraints to the model.

Notation

Indexes:

n: hierarchical stage level index

i_n: product family index

j_n: facility family index

t: time index

Parameters:

$cprod_{n i_n j_n t}$: production cost at stage n, of product i_n, at facility j_n, at period t

$cship_{ni_n j_n j_{n+1} t}$: shipping cost at stage n, of product i_n, from facility j_n to facility j_{n+1} at period t

c_{nj_n} : production capacity at stage n of facility j_n

l_n: lead time at stage n

$X_{ni_n t}$: total production at stage n of product i_n at period t (to be provided by the aggregate model)

$D_{ni_n t}$: total demand at stage n of product i_n at period t (to be provided by the aggregate model)

Decision Variables:

$x_{ni_n j_n t}$: number of units produced at stage n, of product i_n, at facility j_n, at period t

$d_{ni_n j_n t}$: number of units demanded at stage n, of product i_n, at facility j_n, at period t

$y_{ni_n j_n j_{n-1} t}$: number of units shipped at stage n, of product i_n, from facility j_n to facility j_{n-1} at period t

In this model, we are not trying to disaggregate all of the periods; we only focus for the first period of each stage. The first period of stage n is T_n+1. You can see details at previous section.

The objective function is:

$$\min \sum_{n=1}^{N} \sum_{i_n=1}^{I_n} \sum_{j_n=1}^{J_n} cprod_{ni_n j_n T_n+1} x_{ni_n j_n T_n+1} + \sum_{n=1}^{N-1} \sum_{i_n=1}^{I_n} \sum_{j_n=1}^{J_n} \sum_{j_{n+1}=1}^{J_{n+1}} cship_{ni_n j_n j_{n+1} T_n+1} y_{ni_n j_n j_{n+1} T_n+1} \tag{5.6}$$

As in aggregate model, in this model the objective function also consist of two parts. The first part is the production costs. But unlike aggregate model, the second part consists of shipping cost.

subject to:

$$\sum_{j_n=1}^{J_n} x_{ni_n j_n T_n+1} = X_{ni_n T_n+1}, \quad n = 1\ldots N, \quad i_n = 1\ldots I_n \tag{5.7}$$

Constraint (5.7) disaggregates aggregate productions at stage *n* to facilities. In every stage each product can be produced at each facility which is indicated with j_n. This aggregation is done for the first planning period of each stage only. This is an advantage of hierarchical production planning as detailed production planning of all periods is not necessary.

$$\sum_{j_n=1}^{J_n} d_{ni_n j_n t} = D_{ni_n t}, \quad n = 1\ldots N, \quad i_n = 1\ldots I_n, \quad t = T_n + 1\ldots T + T_n + 1 \tag{5.8}$$

Constraint (5.8) is similar to constraint (5.7) but this time with demand, not production. Demand should be disaggregated for all period to be able to implement consistency and coherence constraints later.

$$x_{ni_n j_n T_n+1} \geq d_{ni_n j_n T_n+1}, \quad n = 1\ldots N, \quad i_n = 1\ldots I_n, \quad j_n = 1\ldots J_n \tag{5.9}$$

Constraint (5.9) assures that production exceeds demand for each product and facility.

$$\sum_{i_n=1}^{I_n} x_{ni_n j_n T_n+1} \leq c_{nj_n}, \quad n = 1\ldots N, \quad j_n = 1\ldots J_n \tag{5.10}$$

Constraint (5.10) assures the capacity constraints. As many products can be produced at each facility, total production can not exceed the capacity of each particular facility. It is assumed that each facility at a stage produces all the same products and the capacity requirement of each product is the same. These assumptions can be improved.

$$d_{ni_n j_n T_n+1} = \sum_{j_{n-1}=1}^{J_{n-1}} y_{ni_n j_n j_{n-1} T_n+1}, \quad n = 2 \ldots N, \ i_n = 1 \ldots I_n, \quad j_n = 1 \ldots J_n \tag{5.11}$$

Constraint (5.11) is the first of shipping constraints. This constraint considers outgoing shipping so we start at stage 2 as we don't ship from stage 1. Left side of the equation is the demand made to the facility j_n. This demand should be shipped to the facilities at the upper stage (n-1). So the products are being sent from stage n. They will be sent to any facility at stage n-1 (where facilities are denoted as j_{n-1}). In the right side of equation we summarize the total number of products sent to each facility j_{n-1} at stage n-1 and we find total item send from the facility j_n. This equation should be assured for every product i_n. As for production this is only calculated for the first planning period of each stage.

$$\sum_{i_n=1}^{I_n} f_{ni_n i_{n+1}} x_{ni_n j_n T_n+1} = \sum_{j_{n+1}=1}^{J_{n+1}} y_{n+1 i_{n+1} j_{n+1} j_n T_{n+1}+1}, \quad n = 1 \ldots N-1, \ i_{n+1} = 1 \ldots I_{n+1}, \quad j_n = 1 \ldots J_n \tag{5.12}$$

Constraint (5.12) is very similar to constraint (5.11) but this time, we consider incoming shipping so we end at stage N-1 because we don't receive anything to stage N. In the left side we calculate the number of raw material required for the facility. We find that value by multiplying number of production by the coefficient f. We summarize that value for all products so we can find total raw material requirement. This value should equal to total incoming shipping which consist right side of the equation.

Note the difference between constraints (5.11) and (5.12). In constraint (5.11) we summarize outgoing shipping, and in constraint (5.12) we summarize incoming shipping.

$$\sum_{t=T_n+1}^{T+T_n+1} X_{ni_n t} \geq \sum_{j_n=1}^{J_n} \left(\sum_{t=T_n+1}^{T+T_n+1} d_{ni_n j_n t} - s_{ni_n j_n T_n+1} \right), \quad n = 1 \ldots N, \ i_n = 1 \ldots I_n, \ t = T_n + 1 \ldots T + T_n + 1 \tag{5.13}$$

$$\sum_{t=T_{n+1}}^{T} X_{ni_n t} \geq 0, \quad n = 1 \ldots N, \quad i_n = 1 \ldots I_n, \quad t = T_n + 1 \ldots T + T_n + 1 \tag{5.14}$$

These are the two consistency and coherency constraints as proposed by Ershler, Fontan and Merce [21].

5.2.2. Example

Once aggregate data is acquired, we will disaggregate this data to find individual productions for each facility. We are only interested to the first planning period of each stage. But to maintain consistency and coherence we'll disaggregate demands for all periods too.

Diagram 5.4 shows the disaggregation process for stage 3.

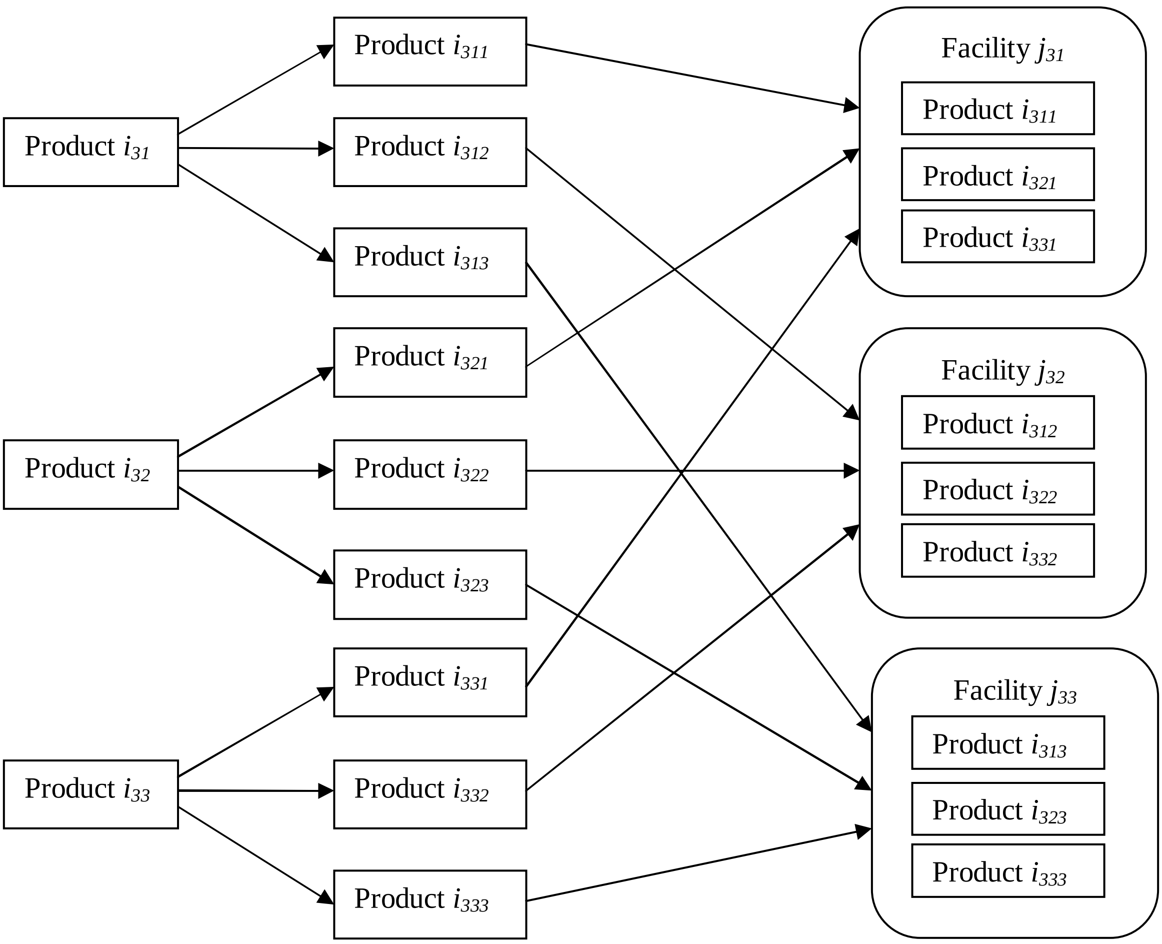

Figure 5.4 Disaggregation Procedure

Each product is distributed among facilities. In stage 3 there are 3 facilities, thus each product is distributed to these 3 facilities. All of the products are distributed to 3 facilities. As a result we obtain 3 facilities producing 3 products each. These production orders are given to each facility. This process consist our models disaggregation part.

The same process also applies to stages 2 and 1.

Example data are given in following tables.

Table 5.9 Production Capacities

Production Capacities	Facility 1	Facility 2	Facility 3
Stage 1	100	-	-
Stage 2	200	150	-
Stage 3	350	250	400

Table 5.10 Production Costs

		Product		
Stage	Facility	1	2	3
3	1	35	30	25
	2	25	20	15
	3	20	25	15
2	1	38	42	
	2	27	35	
1	1	50		

Table 5.11 Inventory Costs

		Product		
Stage	Facility	1	2	3
3	1	4	3	2
	2	5	4	3
	3	6	5	4
2	1	4	2	
	2	5	3	
1	1	5		

Table 5.12 Shipping Costs

	To	Stage 2		Stage 1
From	Facility	1	2	1
Stage 3	1	6	8	-
	2	7	5	-
	3	9	4	-
Stage 2	1	-	-	12
	2	-	-	11

Using these data we solved the disaggregation model and found the following solution

Table 5.13 Obtained Productions

		Product		
Stage	Facility	1	2	3
3 (at period 1)	1	8	117	200
	2	0	133	200
	3	242	0	0
2 (at period 2)	1	29	133	-
	2	171	0	-
1 (at period 4)	1	85	-	-

Table 5.14 Obtained Shipping

	To	Stage 2						Stage 1	
From	Facility	1			2			1	
	Product	1	2	3	1	2	3	1	2
Stage 3 (at period 1)	1	0	0	342	8	0	0	-	-
	2	58	0	0	59	133	0	-	-
	3	0	200	0	199	0	0	-	-
Stage 2 (at period 2)	1	-	-	-	-	-	-	0	170
	2	-	-	-	-	-	-	85	0

As seen in this example total production quantities for facilities in stage 1 is equal to 325 which is the aggregate production quantity. We have been able to disaggregate total production through the facilities. On the other hand we didn't have to calculate all production for all periods but the first one. Thus we have decreased the number of calculation required. Also we have calculated the shipping. In the shipping table we have the optimum shipping routes in order to minimize the shipping costs.

In summary, in the first model we have calculated the aggregate production amounts considering production and inventory costs for the entire planning horizon. In this model we didn't take into account individual facilities so been able to reduce number of decision variables. In the second model we have disaggregated these production quantities. We have distributed production load among the facilities. In this model we have taken into account production and shipping costs. Doing this disaggregation we had only to deal with the first period production. This also decreased the number of decision variables.

As a result we have been able to apply successfully the model to a hypothetical example. This model can also be modified and expanded to meet specific needs. This fact makes this model very flexible.

6. Conclusion

The objective of this study was to construct a method which would simplify decision making process for supply chain management. We have started by introducing the supply chain concept and the logistic concept from which supply chain inherited. We have presented its evolution and key features and requirements of an efficient supply chain. We have talked about traditional methods to solve these problems and there inconveniences.

The main inconvenience was the complexity and difficulty to solve such problems in a reasonable amount of time. As time is very precious in today's competitive environment we tried to figure out an alternative approach to supply chain management. As an alternative we have considered to adopt hierarchical production planning approach. This approach was first developed to solve complex production problems but its use in supply chain management was limited. We have made a brief introduction to production planning approach.

Next we have constructed our model and determined its hierarchies. We have tried to form a model as flexible as possible. This model can be customized and other constraints and variables may be added if needed. We presented the model and its sub-models. We didn't think of the sub-models as separated but also supplied required constraint to unify them in order to overcome infeasibilities associated to loss of data on aggregation process.

With hierarchical approach, as we lose some data we were not able to find the optimal solution but the main objective was to find an adequate solution in a reasonable amount of time. Presenting the models we have inserted an illustrative example to be able to better analyze the model. We also have proven this model is applicable to real life problems.

Also, as the model is very flexible, it may be modified to solve different types of problems with a hierarchical form. This can be achieved by changing variables and constraints and also by introducing new variable and constraints if needed.

With this study we have been able to construct a flexible and easy to apply model to solve complex problems in a reasonable of time. We have applied our approach to a supply chain model and solved a simple example to illustrate it. We think this approach will be useful for many real life problems.

The main inconvenience of this model is we had to move data between the models manually and also for just one period. This model can be improved developing a heuristic which will allow exchanging data automatically between the hierarchies. Also rolling horizon concept can be integrated to the model, so the model can be simulated for several periods also it can be adjusted every period against fluctuations.

Also, as a future study, the performance of this model can be compared to a monolithic approach. The proximity of the results to the optimal can be examined. The calculation time benefits can be observed. This would allow us to better understand real benefits and costs of a hierarchical method.

References

[1] İçen, Y., *Modelisation des Chaines d'Approvisionnement par l'Approche de Plannification de la Production Hierarchique, Master Thesis* Galatasaray University, İstanbul (2003).

[2] Hax, A.C., Candea, D., *Production and Inventory Management*, Prentice Hall Inc, New Jersey, (1984).

[3] Akbari Jokar, M.R., Frein, Y., Dupont, L., “Sur l’Evolution du Concept de Logistique”, http://www.uqtr.uquebec.ca/rirl2000/AKB_FRE.PDF, (2000).

[4] Miller T., *Hierarchical Operations and Supply Chain Planning*, Springer-Verlag, London, (2001).

[5] Robeson, J.F., Copacino, W.C., *The Logistics Handbook*, The Free Press, New York, (1994).

[6] Council of Logistics Management, Oakbrooks, (1985).

[7] Ross, D.F., *Competing Through Supply Chain Management: Creating Market-Winning Strategies Through Supply Chain Partnerships*, Chapman and Hall, (1997).

[8] Dupont, L., *La Gestion Industrielle*, Hermes, Paris (1998).

[9] Brossard, J.F., “La Chaîne d'Approvisionnement: Les Caractéristiques d’Une Chaîne d’Approvisionnement Efficace”, http://www.allbodies.com/Chrpniques/chaine_approvisionnement/article01.shtml, (2002).

[10] Martin, S., Voehl, F., *Macrologistics Management: A Catalyste for Organizational Change*, CRC Press, Florida, (1998).

[11] Handfield, R.B., Nichols, E.L., *Introduction to Supply Chain Management*, Prentice Hall, New Jersey, (1999).

[12] Hax, A.C., Meal, H.C., *Hierarchical Integration of Production Planning and Scheduling*, TIMS Studies in Management Science, Vol. 1, Logistics, North Holland-America Elsevier, Amsterdam, (1975).

[13] Bitran, G.R., Hax, A.C., "On The Design of Hierarchical Planning Systems", *Decision Sciences*, 8, (1997).

[14] Graves, S.C., "Using Lagrangean Techniques to Solve Hierarchical Planning Problems", *Management Science*, 28(3), (1981).

[15] Erol, M., *La Plannification et la Contrôle de Production: L'approch Hiérarchique*, Mémoire de DEA en Génie Industriel, Laboratoire d'Automatique de Grenoble, (1996).

[16] Anthony, R.N., *Planning and Control Systems: A Framework For Analysis*, Harvard University, Boston, (1965).

[17] Boksma, K., "Aggregation and the Design of Models for Medium Term Planning or Production", *European Journal of Operational Research*, 10, (1982).

[18] Wijngaard, J., *On Aggregation in Production Planning*, Elsevier Scientific Publishing, Amsterdam, (1982).

[19] Gelders, L.F., Van Wassenhove, L.N., "Hierarchical Integration in Production Planning: Theory and Practice", *Journal of Operations Management*, 3(1), 27-35, (1982).

[20] Fontan, G., Hetreux, G., Mercé, C., *Plannification Hierarchique de la Production: Aggregation du Temps et Robustness*, Rapport LAAS, no 93377, (1993).

[21] Erschler, J., Fontan, G., Mercé, C., "Consistency of the Disaggregation Process in Hierarchical Planning", *Operations Research Society of America*, 34(3), 464-469, (1986).

[22] Laserre, J.B., Mercé, C., "Robust Hierarchical Production Planning Under Uncertainty", *Annals of Operational Research*, 26, 72-87, (1990).

[23] Gabbay, H., *A Hierarchical Approach to Production Planning, Technical Report No: 120*, Operations Research Center, M.I.T., Cambridge, (1975).

[24] Gfrerer, H., Zäpfer, G., "Hierarchical Model for Production Planning in the Case of Uncertain Demand", *European Journal of Operational Research*, 86, 142-161, (1995).

[25] Beamon, B., “Supply Chain Design and Analysis: Models and Methods”, *International Journal of Economics*, 55, 281-294, (1998).

[26] Petrovic, D., Roy, R., Petrovic, R., “Modelling and Simulation of a Supply Chain in an Uncertain Environment”, *European Journal of Operational Research*, 109, 299-309, (1998).

[27] Petrovic, D., Roy, R., Petrovic, R., “Supply Chain Modelling Using Fuzzy Sets”, *International Journal of Production Economics*, 59, 443-453, (1999).

[28] Li, D. O’Brien, C., “Integrated Decision Modelling of Supply Chain Efficiency”, *International Journal of Production Economics*, 59, 147-157, (1999).

[29] Özdamar, L., Yazgaç, T., “A hierarchical Planning Approach for a Production-Distribution System”, *International Journal of Production Research*, 37(16), 3759-3772, (1999).

[30] Sabia, E.H., Beamon, B.M., “A Multi-Objective Approach to Simultaneous Strategic and Operational Planning in Supply Chain Design”, *Omega*, 28(5), 581-598, (2000).

[31] Goetschalckx, M., Carlos, J.V., Dogan, K., “Invited Review: Modelling and Design of Global Logistics Systems: A Review of Integrated Strategic and Tactical Models and Design Algorithms”, *European Journal of Operational Research*, 143, 1-18, (2002).

[32] Schneeweiss, C., “Distributed Decision Making - a Unified Approach”, *European Journal of Operational Research*, 150, 237–252, (2003).

[33] Schneeweiss, C., Zimmer, K., “Hierarchical Coordination Mechanisms within the Supply Chain”, *European Journal of Operational Research*, 153, 687–703, (2004).

[34] Hurtubise, S., Olivier, C., Gharbi, A., “Planning Tools for Managing the Supply Chain”, *Computers & Industrial Engineering*, 46, 763-779, (2004).

[35] Blackhurst, J., Wu, T., Craighead, C.W., “A Systematic Approach for Supply Chain Conflict Detection with a Hierarchical Petri Net Extension”, *Omega*, In Press, Corrected Proof, Available Online, (2006).

[36] Xie, Y., Petrovic, D., Burnham, K., “A Heuristic Procedure for the Two-Level Control of Serial Supply Chains Under Fuzzy Customer Demand”, *International Journal of Production Economics*, 102, 37–50, (2006).

[37] Axsäter, S., “Feasibility and Optimality of Aggregate Plans”, O.R. Report, 167, (1980).

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