ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

DEMAND FULFILLMENT WITH TIME AND BUDGET LIMITS

M.Sc. THESIS

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Department of Industrial Engineering

Engineering Management Program

JUNE 2017

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Thesis Advisor: Assoc. Prof. Dr. Gülgün KAYAKUTLU

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

ZAMAN VE BÜTÇE LİMİTLERİ DAHİLİNDE TALEP KARŞILAMA

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İsmail Ender Kaba, an M.Sc student of İTU Graduate School of Science Engineering and Technology student ID 507011160, successfully defended the thesis entitled “DEMAND FULFILLMENT WITH TIME AND BUDGET LIMITS”, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my wife and son,

FOREWORD

First, I shall tell that I am grateful to Assoc. Prof. Dr. Gülgün Kayakutlu, my thesis supervisor, for her every kind of support during this study. Her thorough knowledge of supply chain planning and her endless desire to seek the simplest best has always motivated me during my study. It has been a real pleasure to work with her and I hope we will go on new journeys in the future.

I would like to thank ICRON Technologies for their support and contributions to this work.

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ABBREVIATIONS

GSAMS : Graphical Scheduling Modeling Algorithm System
LP : Linear Programming
MIP : Mixed Integer Programming
MILP : Mixed Integer Linear Programming
NLP : Non-Linear Programming

SYMBOLS

b_m : Backorder penalty cost satisfying product group *m*’s forecast later
$B_{m,t}$: Backorder level for product group *m* at the end of period *t*
$c_{p,t}$: Total available capacity of process *p* in period *t* (seconds)
$D_{m,t}$: Open forecasted quantity for product group *m* in period *t*
$d_{o,p}$: Total duration (days) for order *o* in process *p*
$D(t)$: Demand forecast for period *t*
f_o : Planned finish period for order *o*
h_f : Penalty cost for holding finished goods inventory
h_m : Monthly stock keeping cost for product group *m*
$I_{m,t}$: Inventory built up for product group *m* at the end of period *t*
$I^+(0)$: Current on-hand inventory at the warehouse
$I^-(0)$: Total quantity of customer orders currently waiting to be satisfied
k : Pioneering process outcomes
K_m : The set of material codes with product group *m*
L : Replenishment lead-time
m : Product groups
M^+ : A very big number
o : List of all open customer orders
q_o : Total open quantity of order *o*
$Q_{k,p,t}$: Make-to-stock quantity of item *k* from process *p* in period *t*
$\bar{Q}(t)$: Total quantity scheduled for receipt at the start of period *t*.
p : Production process
r_o : The requested period of order *o*
$s_{k,p}$: The unit operation time of item *k* in production process *p*
$s_{m,p}$: Unit operation time for product group *m* in process *p*
ss : Safety stock level
t : Period
$v_o^{(1)}$: Penalty cost for tardiness for order *o*
$v_o^{(2)}$: Penalty cost for earliness for order *o*
$v_k^{(3)}$: Penalty cost for quantity produced to stock for item *k*
$w_{k,p}$: Penalty cost of producing item *k* in process *p*
$w_{m,p}$: Penalty cost for assigning product group *m* to production process *p*

$X_{m,p,t}$ **:** Amount of product group *m* assigned to process *p* in period *t*

$Y_{o,p,t}$ **:** Quantity of order *o*, allocated to resource *p* in period *t*

β_k **:** Minimum lot size for item *k*.

θ_o **:** Tardiness of order *o*

ϑ_o **:** Earliness of order *o*

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DEMAND FULFILMENT WITH TIME AND BUDGET LIMITS

SUMMARY

Globalization and sustained growth of international trade have increased competition in most of the markets. Today, virtually all major firms have a significant and growing presence in business outside their country of origin. Transfers between subsidiaries of the same company account for most of the trade between industrialized countries. Many companies recognize the opportunities for selling their products in several new markets through a number of sales channels. The main focus for an enterprise is to stabilize the demand, price, cost and risk fluctuations for their certain business areas and to feed constantly their sales channels and to take the right position in changing market conditions. Better logistics, removal of trade barriers, opportunities in the emerging markets, improved communications in businesses and among consumers are the main factors behind scenes of this new world approach.

Due to increasing competition, companies are working with very low-profit margins. To increase profits, sustain their operations and compete, companies are aiming to reduce operational costs such as production, transportation, setup and inventory holding costs. For brand owners and manufacturers, solving the response management need in their demand management and fulfillment operations represents the largest opportunity to increase customer satisfaction, enhance margins and attain more predictable revenue in the entire value chain.

The main objective of this study is to develop a decision support system for supply chain network that will reduce operational costs, increase customer service levels, and increase the sensitivity of the planning department to rapidly changing conditions where profit margins are low. A planning system consisting of integrated models such as integrated and daily capacity planning and it is solved by a mixture of optimization methods and heuristic methods. The planning system is implemented in the ICRON Supply Chain Optimization System. With this study enhanced customer service level, improved responsiveness, improved due dates are observed.

ZAMAN VE BÜTÇE LİMİTLERİ DAHİLİNDE TALEP KARŞILAMA

ÖZET

Son yıllarda artan küreselleşme, beraberinde şirketler için oldukça rekabetçi bir ortam yaratmaktadır. Şirketlerin ürettikleri ürünler rakiplerinin ürünleri ile tamamen ikame edilebilir hale gelmiştir. Özellikle büyük şirketler menşe ülkeleri dışındaki işletmelerde önemli ve artan bir varlığa sahiptir. Bu durum beraberinde aynı şirketin işletmeleri arasındaki ticareti arttırarak, piyasadaki gücünü perçinlemektedir.

Şirketler bir dizi satış kanalı vasıtasıyla müşteri taleplerini karşılamaya çalışmaktadır. Şirketlerin temel amacı, satış kanallarını sürekli besleyerek geç teslimatlardan ötürü satışlarını rakiplere kaptırmayı önlemek ve değişen pazar koşullarında doğru pozisyon almaktır.

Firmalar, müşteri memnuniyetini, onların temel gereksinimleri ve asgari müştereklerin ötesindeki beğenilerini karşılamak üzere ürün ve hizmet sağlamak anlayışı içinde değerlendirmektedir. Bu bağlamda satış öncesi ürün veya hizmet tasarımından başlayan ve satış sonrası hizmetlere kadar devam eden süreçte mükemmelleşmeye çalışılmaktadır.

Bu süreçte, müşterinin pazarda ürünü almak istediği anda, kendisine en yakın bir yerde ve istediği miktarda bulabilmesi, müşteri memnuniyeti için kilit rol oynamaktadır. Çünkü ürün ya da hizmet, satın alınmak istenen anda mevcut ya da yeterli değilse, ürün ya da hizmet müşterinin isteklerine en iyi biçimde cevap verse de ya da satış sonrası hizmetler mükemmel olsa da ürün ya satılamamakta ya da müşteri memnuniyetsizliği yaşatmaktadır. Dolayısıyla sunulan ürün veya hizmetin gerektiği anda yeterli miktarda bulunması müşteri memnuniyetini doğrudan ve en yüksek derecede etkileyecektir.

Diğer yandan tüm talepleri zamanında ve yeterli miktarda karşılayacak kadar yüksek müşteri hizmet düzeyine sahip olmak için stokların o derece yüksek olması gerekir. Böylece büyük stoklar sayesinde siparişlere her zaman yanıt verilebilir. Ancak stok tutmanın bir maliyeti olduğuna göre, müşteri memnuniyetini yükseltmek için stok maliyetlerinin artması gerekmektedir.

Artan rekabet nedeniyle şirketler hem müşteri memnuniyeti sağlayarak hem de maliyetleri kontrol ederek çok düşük kar marjları ile firmanın yaşamına devam etmesine çalışmaktadırlar. Karlarını artırabilmek, faaliyetlerini devam ettirebilmek ve rekabet edebilmek için şirketler üretim, nakliye, setup ve stok tutma maliyetleri gibi operasyonel maliyetleri düşürmeyi hedeflemektedir.

Literatür taraması talep karşılama ve üretim planlama problemlerine yönelik kullanılan değişik modelleri anlatmaktadır. Doğrusal programlama, karma tam sayılı doğrusal programlama, doğrusal olmayan programlama en çok kullanılan modelleme yöntemleridir.

Karma tamsayılı modeller genel olarak sezgisel ve algoritmik yöntemleri ile çözülmektedir. Sezgisel yöntemler sonucun doğruluğunun kanıtlanabilir olup

olmadığını önemsenmez. Çeşitli alternatif hareketlerden etkili olanlara karar vererek iyiye yakın çözüm yolları elde etmeyi amaçlar. Makul bir süre içerisinde bir çözüm elde edeceklerini garanti ederler. Genellikle en iyiye yakın olan çözüm yoluna hızlı ve kolay bir şekilde ulaşırlar.

Algoritmik yöntemler ise genel olarak iki farklı teknik kullanırlar. Dal-sınır yöntemi ile kesme düzlemi yöntemi. Dal-sınır yöntemi sistematik bir şekilde olurlu çözümlerin sayılarak en iyi tamsayılı çözümün bulunması için kullanılır. Belirli sayıda olurlu çözümü inceleterek (küçük bir kısmının inceleneceği ümidi ile) en iyi çözümü garantili bir şekilde bulur. Kesme düzlemi yönetiminde ise amaç kısıtlar ekleyerek tamsayılı değerler barındıran en iyi olurlu çözüme ulaşmaktır. Eklenecek özel kısıtlara kesme adı verilir. Eklenecek kesmelerin ilgili model için belirli kriterleri sağlaması gerekmektedir. Karar değişkeni sayısı arttıkça, çözüme ulaşmak için tekrarlanması gereken yineleme sayısı artmaktadır. GUROBI ve CPLEX gibi çözücülerde, dal sınır algoritması ve kesme düzlemi algoritmalarının birlikte kullanıldığı dal-kesme algoritmaları kullanılır.

Bu çalışmada aylık bazda bütünleşik üretim planlama modeli ile ürün grupları bazında çözüm sağlanırken, çıkan sonuçlara uygun olarak ürün grubu içindeki ürünlerin planı günlük bazda bir model ile ele alınmaktadır. Bunları yaparken Karma tam sayılı doğrusal programlama yönetimi kullanılıştır.

İlk model olan bütünleşik üretim planlama, talep gecikmelerini enazlayacak şekilde ürün gruplarının sıralamasının ve üretim proseslerine atamasının yapılmasını garanti eder. Bunu yaparken kaynak kapasiteleri, üretim maliyetleri ve üretim süreçlerindeki öncelik tercihleri dikkate alınmaktadır. Modelde zaman dilimi olarak ay kullanılmaktadır.

İkinci model ise bütünleşik modelde belirlenen üretilecek ürün gruplarının içinde üretilmesi gereken ürünlerin optimum seviyede, hazırlık süreleri enazlanacak şekilde sıralanmasını garanti eder. Bunu yaparken kaynak kapasiteleri, ürünlerin öncelik tercihleri, üretim maliyetleri, geç karşılama, erken karşılama maliyetleri de dikkate alınmaktadır. Model 1 günlük zaman dilimi üzerinden çalışmaktdır.

Modellerde kullanılan kısıtlar, üretimin doğası gereği olan kaynak kapasitesi, hazırlık süresi gibi ve üretimi doğrudan etkileyen tüm faktörlerdir. Bunun dışında müşteri servis seviyeleri ile ilişkilendirilen taleplerin erken ve geç karşılanması gibi kısıtlar da modelde ayrıca dikkate alınmaktadır. Özellikle çözümün istenilen kalitede olması için makina ve işyeri öncelik seçimleri ile aynı dönemde hazırlık ve geçiş süresi en az olan ürün-ürün gruplarının tercih edilmesi büyük önem taşımaktadır.

Bu çalışmanın temel hedefi, operasyonel maliyetleri düşürecek, müşteri hizmet düzeyini arttıracak ve planlama bölümünün hızlı değişen koşullara daha iyi adapte olmasını sağlamak için görünürlülüğü arttıracak bir tedarik zinciri karar destek sistemi geliştirmektir. Bütünleşik ve günlük kapasite planlama gibi entegre modellerden oluşan planlama sistemi, optimizasyon yöntemleri ve sezgisel yöntemlerin bir karışımı ile çözülür. Planlama sistemi, ICRON Tedarik Zinciri Optimizasyon Sisteminde uygulanmıştır. ICRON sisteminde geliştirilen modeller uygulamanın hızlı bir şekilde geliştirilmesine de imkan sağlamıştır.

Oluşturulan modeller ve entegre bir tedarik zinciri sistemi sayesinde planlama daha görünür ve yönetilebilir hale getirilmiştir. Bu sayede departmanlar arası iletişim güçlenmekte, her bir departman planı ve plandaki değişimlerin talep yönetimine olan olas etkilerini daha net bir şekilde görebilmektedir.

Üst yönetim tarafından sürekli analiz ve talip edilen, geç karşılanan talep oranlarında azalma ve talepleri mevcut stoklardan karşılama oranlarında bir artmanın en kısa sürede gözlenebileceği öngörülmektedir.

1. INTRODUCTION

Demand fulfillment is an important concept that provides a competitive advantage in today's business environment with an inflating worldwide competition consequently, it has become increasingly popular in both the service and the manufacturing sector. It builds customer loyalty and recognition, therefore has a large impact on profitability. Accordingly, Davis et al. [56] state that "customer satisfaction is not the end objective, but rather an intermediate way station". Customer satisfaction, which may be achieved via various factors such as low price, high quality, short delivery times, leads to customer loyalty, which in turn results in customer retention, and consequently increasing sales and finally providing higher profits. According to the study of Reicheld et al. [57], covering a wide array of industries, "a 5 percentage shift in customer retention results in 25-100% profit". Since most of the manufacturers and companies are aware of this significant impact of customer retention on profitability, they focus more on increasing customer satisfaction.

Meeting the customer demand within short and assured delivery times is crucial for achieving customer satisfaction. Besides, in a competing business environment, short delivery times are quite an effective tool for the companies to differentiate themselves from their rivals. Therefore, this triggers the manufacturers to shorten their response times with effective capacity planning and improve their production processes in order to be able to assign shorter due dates, which will extend sales and reduce costs. Since capacity improvement can be done to a certain extent, the improvements in the production capacity can be supported with an effective due-date management.

For an effective due-date management, the manufacturers have to deal with the tradeoff between quoting small due-dates in order to increase customer satisfaction and achieving them with a constrainted production capacity. If the due-dates are set long, companies may lose customers because of the customers' limited delivery time flexibility, which may vary according to the industry and product. On the other hand, if the due-dates are unrealistically short to achieve with the available production capacity, the customers again may have to wait a considerable amount of time for the delivery, and additionally, the due-date reliability of the company may deteriorate. Therefore an effective due-date quotation policy is an essential tool used in practice for production control which has a significant impact on enhancing lead times and customer satisfaction as addressed in Patil et al. [58].

In order to extend customer satisfaction, many firms may prefer to produce customized products for their customers, which in turn increase the production costs and delivery times as well. In such a business environment with changing customer needs and expectations, companies producing customized products can remain competitive by utilizing suitable due-date management policies in order to condense their lead times and increase their due-date reliabilities. However, the effect of increasing demand for customized products does not only shorten lead time but also propagates new concepts such as "delivery time differentiation". Especially companies having customers from diverse segments may encounter different delivery time sensitivities. Therefore, we can say that due-date quotation is an effective tool which may serve different purposes from capacity planning to product differentiation.

In this study, multi-level mixed integer model is developed to minimize total cost and tardiness while increasing on-time delivery performance and demand satisfaction.

The thesis is organized as follows: In Chapter 2, we present an overview of the related literature about the research, where problems in this thesis are considered. In Chapter 3, the basics of optimization methodology are explained and the selected optimization techniques are expressed. In Chapter 4, contains the descriptions of three models in detail. In Chapter 5, the details of implementation of three models are given. Parameters of the study and how they are integrated into the problem are expressed. Finally, in Chapter 6 a summary of the implementation results are mentioned.

2. LITERATURE REVIEW

The problems that we consider in this study (capacity allocation, demand optimization, distributed demand handling) has received a significant amount of interest in the literature. We refer [1] for a complete treatment of Supply Chain planning using mathematical programming methods. Mula et al. [2] provide a review of literature in production and transportation planning, where an extensive variety of mathematical programming methods, such as linear programming, mixed integer programming, non-linear programming, stochastic programming etc., are used in tactical decision levels.

In literature, there exist various approaches to different extensions of aggregate production planning problem. Alain [3] and Akartunali et al. [4] work on solving Mixed Integer Programming (MIP) formulations of production planning problem, where fixed or setup costs are considered. Alain [3] proposes a primal-dual approach to deal with capacitated production planning problem where fixed production costs are involved. Since fixed costs are considered in the model, production planning problem is formulated as a MIP, where obtaining optimal solutions are only possible for very small instances. Akartunali et al. [4] cope with a heuristic approach to multilevel production planning where setups are considered in MIP model formulated for permitted production planning problem. In the proposed heuristic approach, they combine Linear Programming (LP)-and-fix and relax-and-fix heuristics.

Fumero [5] and Jolayemi et al. [6] consider production planning problem on a network of production plants. Both studies formulate the problem as a MIP model.

Fumero [5] uses Lagrangian relaxation methods to solve production planning problem where the manufacturing organization is divided among a number of plants and size, production plant and resource of production lots sizes should be determined.

Jolayemi et al. [6] specify the production requirements in all plants, whereas they also evaluate subcontracting needs in case of capacity shortages.

Kim and Kim [7] integrate classical LP model with simulation to find a capacity feasible production plan. The main concern of the study is that the production lead times are not necessarily in accordance with the time buckets of the LP model. To modify the use of capacity they propose new parameters called effective loading ratio and effective utilization factor to the capacity constraint of LP model. Those parameters are determined by the simulation, where the production plan generated by LP is used.

Another study where lead times are considered in modeling approach is [8]. Here, the released production order at any time period can only be satisfied after a certain amount of periods. Fulfillment of dependent demands and capacity usage constraints are modeled concerning that fact.

Leung et al. [9] formulate a goal programming model for aggregate production planning problem in a multi-plant production environment with constrainted storage and resource capacities, where goals are profit maximization, minimizing defect and repair costs and maximizing resource utilization. Fuzzy multi-objective linear programming approach for aggregate production planning problem is developed in [10]. Same authors work on the development of possibilistic linear programming model for aggregate production planning problem in [11].

Another extension to production planning problem is implemented by [12], where there exists flexibility in demand satisfaction. That is, from a number of demands for a time period, the model may choose to fulfill only some quantity of demands. The objective is to maximize profit where setup costs and inventory holding costs are taken into account. Authors obtain some results for the optimal solution of the problem such as in the optimal solution, no demand is partially fulfilled and demands are not partially delivered.

In literature, there is some hybrid flow shop scheduling problems where optimization techniques are used. Mendez et al. [13] review the use of optimization techniques for solving scheduling problems. Ruiz et al. [14] focus on studies on hybrid flow shop scheduling problem. In [15], a wide-ranging study on scheduling problems with setup times is supplied.

In [16], MIP models and heuristic approaches are offered to model realistic scheduling problems in hybrid flow shops, where sequence-dependent setup times, machine qualifications and priority constraints are taken into account. Another MIP formulation is recommended in [17] for a real life problem experienced in a manufacturing firm in electronic and semiconductor industry. A case study in electrical appliance manufacturer is given in [18], where MIP models are used.

A MIP formulation is suggested in [19], where the objective is to maximize resource usage and also to minimize tardiness and earliness penalties of orders. Sawik [20] recommends a MIP model for flexible flow shops where standard buffer spaces are limited. Harjunkoski and Grossmann [21] merge MIP and constraint programming models to solve multi-stage scheduling problems. Using MIP, they first commit production batches to resources. Sequencing of batches is performed using constraint programming method. Prasad and Maravelias [22] expand a mixed integer programming model for manufacturers with batch processing. The model is composed of three decision phases: deciding production batches, assigning batches to units and sequencing batches assigned to each unit.

The problem reviewed in [23] is multi-product multi-stage scheduling problem in the pharmaceutical industry. Authors come up with two alternative MIP formulations and a solution approach for real life problems, where they dissolve solution procedure into two steps, i.e. constructive and improvement steps. In constructive step, they schedule orders one by one using MIP model until each order is scheduled and a feasible solution is obtained. In improvement step, they re-order batches until no improvement is obtained. Mendez et al. [24] cope with multi-stage flow shop scheduling problem in batch facilities, where they suggest a mixed integer linear programming formulation.

Several studies have concentrated on designing combined methods for solving production planning and scheduling problems (e.g., [25, 26, 27]). Bhatnagar et al. [28] specify the problem of integrating aggregate production planning and short-term detailed scheduling decisions, where various decisions are taken in different planning levels.

They integrate those decisions by suggesting a planning scheme with feedback mechanisms among different levels. Xue et al. [29] merge aggregate production planning and sequencing problems in a hierarchical planning system where sequence-dependent family setups exist. Production planning and scheduling problems in a hybrid flow shop are combined in a decision support system in [30]. Authors first solve a linear programming model, where production quantities for each period are determined. The production quantities and lot sizes are given to scheduling module, where scheduling is implemented based on a simulated annealing approach.

Jung et al. [31] suggest safety stock levels avoid demand uncertainty in cost effective supply chain management. Their study determines to use the safety stock level to meet the desired level of customer satisfaction.

Zhang et al. [32] define an integrated solution framework which merges scatter evolutionary algorithm, fuzzy programming and stochastic chance-constrained programming model for production planning problem considering the trade-offs between inventories, production costs, and customer service level. The study demonstrates that an integrated solution framework is effective to generate robust production plans under price and demand uncertainties in the market.

Fildes et al. [33] simulate how to demand uncertainty and forecast error effect on supply chain management both production planning and service level side.

Croston [34] creates a method to overcome the fluctuations of stock levels where intermittent demands occur. His study also shows that safety stock levels for intermittent demands must be calculated carefully not only balance unused stocks but also show prompt reactions for demand fluctuations.

Galasso et al. [35] investigate the internal constraints of production process like cycle times, frozen periods etc. to satisfy the customer demand using mixed-integer linear programming where demand is flexible.

Mirzapour et al. [36] focus on aggregate production planning problem under an uncertain environment in a multi-site, multi- period, multi-product system. Their model minimizes total costs as well as customer requirement tardiness in all planning periods using LP-metrics method.

Gupta et al. [37] aim to search out the trade-off between inventory reduction and process cost under demand uncertainty and create a framework of a midterm, multi-facility supply chain planning with a chance constraint programming approach.

Leung et al. [38] formulate a robust optimization model for aggregate production planning problem in a multi-facility production environment, where goals are profit maximization, minimizing production, labor, inventory and workforce changing costs and maximizing resource utilization under diverse economic development scenarios.

Chen et al. [39] formulate a hierarchical decomposition model for a multilevel distribution network in order to minimize lead time, maximize service level and maximize forecast accuracy under demand uncertainty.

Jiang et al. [40] try to figure out the effects of the correlation of iterant components on forecasting and stock control. They use Syntetos-Boylan Approximation method for forecasting.

Altay et al. [41] aim to search out the effects of three different types of correlation on forecasting and stock control of intermittent demand items.

Kazemi et al. [42] formulate robust optimization model in order to determine the tradeoff between the backorder/inventory cost and the customer service level under demand uncertainty. They obtain significant outcomes compared with stochastic programming.

Silva et al. [43] and Faria et al. [44] use a new supply chain management methodology, distributed optimization model, which allows cooperation between all elements in the chain. They use ant colony optimization to solve scheduling and routing problems.

Gupta et al. [45] provide an overview of our previously published works on incorporating demand uncertainty in the midterm planning of multisite supply chains. They propose an effective tool for evaluating and actively managing the exposure of an enterprises assets to market uncertainties.

Chen et al. [46] proposed a model to deal with multiple incommensurable goals for a multi-echelon supply chain network with uncertain market demands and product prices.

Tratar et al. [47] use HoltWinter's method to increase efficiency while improving customer service level as well as reduce total cost.

Lasschuit et al. [48] formulate the mixed-integer non-linear model in order to minimize transport costs, fixed costs, stock-holding costs where planning and scheduling are resource-intensive, complex, rolling processes. They obtain significant improvement in strategic decision taking process.

Nikolopoulou et al. [49] propose a hybrid approach combining mathematical programming and simulation model to solve supply chain management. They obtain an efficient solution to the operational/tactical level of the supply chain management.

Arcelus et al. [50] formulate Bicriteria optimization model in order to determine the ordering and pricing decisions under demand uncertainty.

Petropoulos et al. [51] propose a combination of Croston′s method and Syntetos-Boylan Approximation model in order to explore the efficiency of forecast combinations in the intermittent demand. They obtain improved forecasting performance.

Rajopadhye et al. [52] use the Holt-Winters method in order to forecast the uncertain demand for rooms at a hotel for each arrival day and maximize revenue by making decisions regarding when to make rooms available for customers and at what price.

Sousa et al. [53] formulate an enterprise optimization model in order to optimize the production and distribution plan where an allocation of too many products/customers to the same resource and idle periods in the planning of the bottleneck resources, preventing the whole system from operating at its maximum capacity.

Kourentzes [54] uses Croston′s method model in order to maximize the accuracy of demands.

3. METHODOLOGY

In this study, a mixed integer programming model will be created that will maximize on time delivery and minimize the cost of production. Mixed integer programming (MIP) is a programming model in which some of the decision variables are integers and some are rational numbers. An example of the general structure of mixed integer models can be given as follows [59]

$$\begin{aligned} &Max\ Z = 3x_1 + 2x_2 \\ &x_1 + x_2 \le 6 \\ &x_1, x_2 \ge 0,\ x_1 \text{ integer} \end{aligned} \tag{3.1}$$

Mixed integer linear models are solved with integer modeling methods. These methods are divided into two as heuristic methods and optimization methods.

Heuristic methods are methods that have developed for specialized problem types but do not give the most favorable result but approach the probable result. These methods are preferred when the amount of time and energy required to find the optimal solution is too great.

There are different algorithm approaches for solutions of exact numbered models. Mixed integer models are solved by solution approaches of integer models. These approaches can be grouped as follows [59]:

- Branch-and-bound method
- Cutting plane algorithm

In the branch-and-bound algorithm, which is the most frequently used method for solving the integer models, the model is considered first by ignoring the necessity of the integer number. The solution obtained in this way is called relaxation of linear programming [60]. For the maximization problems; the result obtained by linear programming relaxation is greater than or equal to the value obtained by integer programming (if the linear model has the best result-giving decision variables of an integer number). For minimization problems, the result will be smaller (or equal) as a result of the exact number modeling.

The solution is to select one of the desired variables to be an integer. New constraints related to the value of this decision variable are added. That is if the system gets the best value when $x_1 = 3.5$, the constraints $x_1 \leq 3.5$ and $x_1 \geq 4$ are added to the model. When x_1 reaches the integer value than integer values are started to be searched for the other variables. The algorithm ends when all integer variables get the best value related with the objective function. The example that is given at [59] is shown in Figure 3.1.

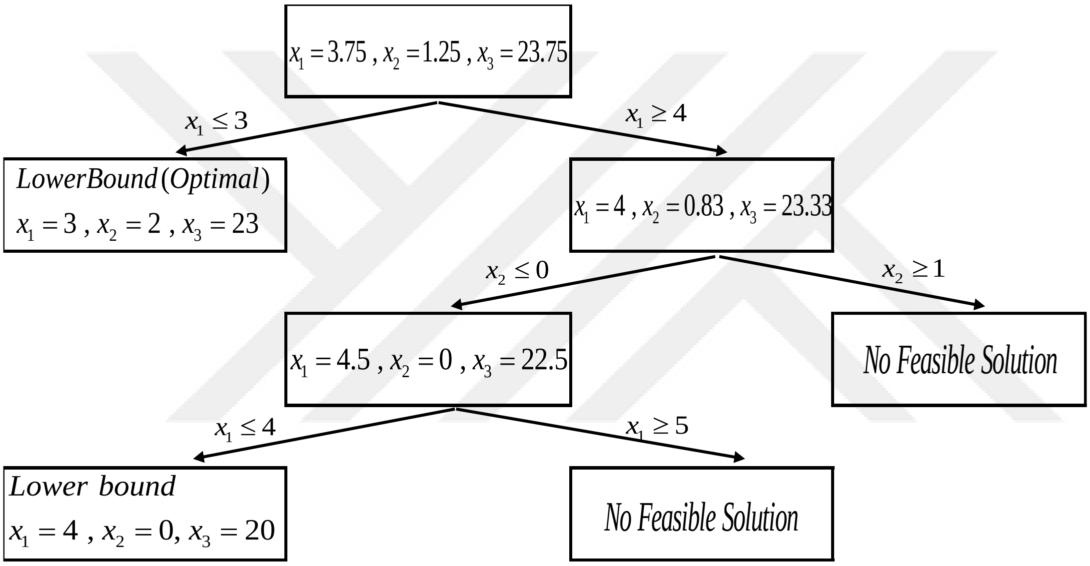


Figure 3.1 : Branch-and-Bound Algorithm Example.

The cutting plane algorithm starts by finding a linear solution like branch-and-bound algorithm [59]. In the subsequent steps of the algorithm, constraints are added to narrow the resulting solution space. Added cuts should not handle possible integer solutions [59]. In Figure 3.2, the general structure of the cutting plane algorithm is visualized. The cuts create new constraints for the model.

The branch-and-bound algorithm is not suitable for solving large-scale problems. As the number of decision variables increases, the number of iterations that must be repeated to achieve the solution increases. Branch and cut algorithms, such as GUROBI and CPLEX, are used as a mixture of branch-and-bound and cutting plane algorithms [61].

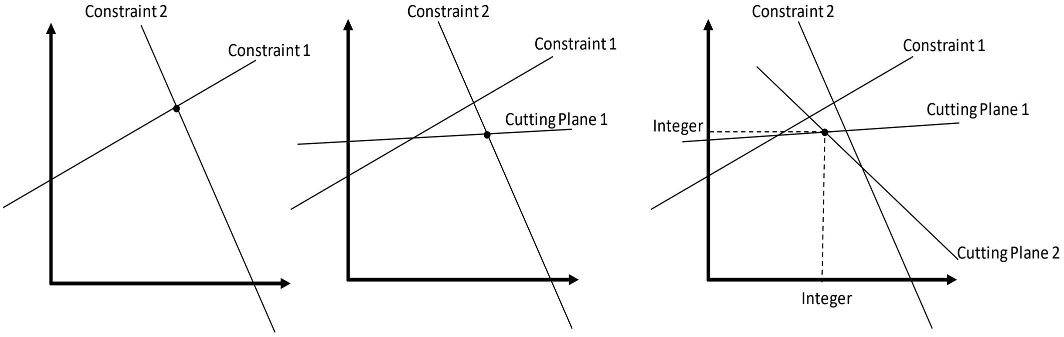


Figure 3.2 : Cutting Plane Algorithm Example.

Given an integer programming problem, the idea of a Branch-and-Cut method is recursively partition the solution set into subsets and solve the problem over each subset. This procedure generates an enumeration tree where offsprings of a node corresponding to the partition of the set associated with the parent node. In each node of the tree, a linear relaxation of the problem is considered by dropping integrality requirements and adding valid inequalities which cut off the fractional solution. To reduce the number of nodes of the tree, it is important to have good lower and upper bounds, good rules to partition the feasible set, good strategies to search for the tree and a good strengthening of the linear relaxation.

The general structure of the branch-and-cut algorithm is given in Figure 3.3.

MIP models are frequently used in areas such as budget planning, network planning, capacity planning where the final decision is made.

The methods, which are used in the literature, are listed in Table 3.1.

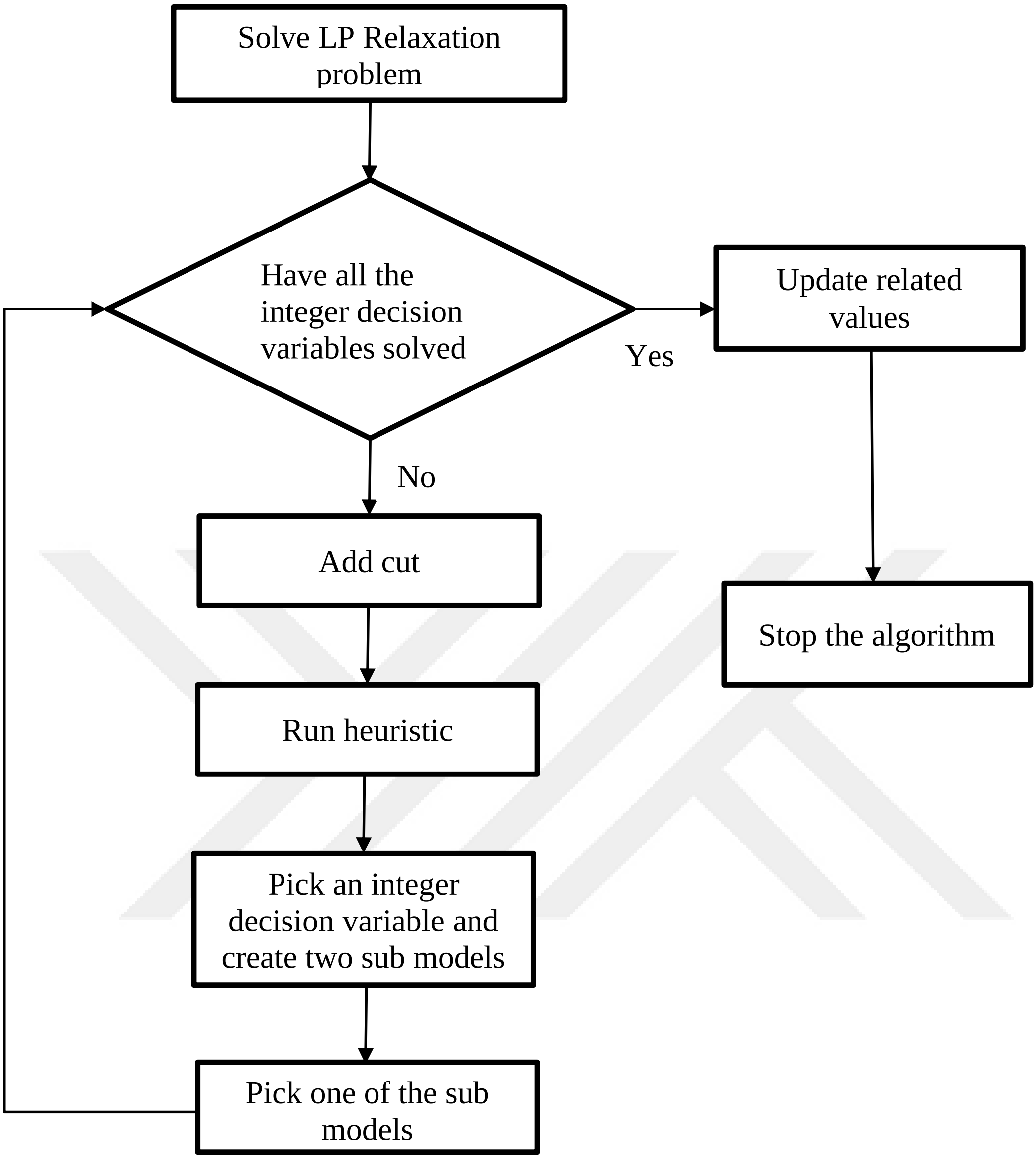


Figure 3.3 : Branch-and-Cut Algorithm Example.

Table 3.1 : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
2	Mula et al.	2010		provide readers with a starting point for mathematical modeling problems in the supply chain production and transport planning aimed at production management researchers	a wide range of mathematical programming methods, like LP, MIP, NLP, stochastic programming	To study the analyzed works, a classification based on the analysis of eight aspects has been proposed: supply chain structure, decision level, supply chain modeling approach, purpose, shared information, model limitations, the novelty contributed and the practical application
3	Alain, G	1999	capacity-constrained production planning problems with variable and fixed costs		MIP	obtaining optimal solutions are only possible for very small instances
4	Akartunalı et al.	2009	heuristic approach to multilevel production planning where setups are considered	minimize the total cost in multi-level lot-sizing problem	LP-and-Fix & Relax-and-Fix	proposed framework for finding good solutions to lot-sizing problems is comparably efficient
5	Fumero, F	1997	The problem of optimally coordinating and integrating complex decisions at the tactical production planning level	allocating production volumes among the different manufacturing facilities, assigning production quantities to alternatives within each plant, determining the production lots for each product on each type of machine in each period	Lagrangean techniques	effective productions in each plant

Table 3.1 (continued) : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
6	Jolayemi et al.	2004	planning production and transportation quantities in multi-plant and multi-warehouse environment with extensible capacities	maximizes total profit over a finite planning horizon	Linear programming	determine the production requirements in all plants, whereas they also evaluate subcontracting needs in case of capacity shortages
7	Kim et al.	2001	find a capacity feasible production plan	cost minimization	classical LP model with simulation	the proposed approach generates the plans with less total costs in fewer numbers of iterations for the cases with and without backlogging.
8	Spitter et al.	2005	constrainted multi-period capacity usage with planned lead times	minimize the total cost of inventory and backorders	Linear Programming	feasible and reliable production plans
9	Leung et al.	2009	planning problem in a multi-facility production environment with limited storage and resource capacities	profit maximization, minimizing defect and repair costs and maximizing resource utilization	A goal programming model	flexible and robust model
10	Wang et al.	2004	multi-product aggregate production planning decision problem in a fuzzy environment	minimize total production costs, carrying and backordering costs and rates of changes in labor levels considering inventory level, labor levels, capacity, warehouse space and the time value of money	Fuzzy multi-objective linear programming	feasible solution with all levels of satisfaction

Table 3.1 (continued) : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
11	Wang et al.	2005	the multi- product aggregate production planning problem with imprecise forecast demand, related operating costs, and capacity	minimize total costs with reference to inventory and labor levels, overtime, subcontracting and backordering levels, and resource capacity.	possibilistic linear programming model	efficient solution and overall degree of decision maker satisfaction with determined goal values
12	Merzifonluoglu et al.	2006	determine optimal levels of demand, production, and inventory for every planning period when flexibility exists in selecting demands and their delivery timing	to maximize profit where setup costs and inventory holding costs are taken into consideration	Linear Programming	optimal solution of the problem where no demand is partially satisfied and demands are not partially delivered.
13	Mendez et al.	2006	the great diversity involved in short- term batch scheduling		MILP	
14	Ruiz et al.	2010	The scheduling of flow shops with multiple parallel machines per stage is a complex combinatorial problem		Scheduling	optimal schedules
15	Allahverdi et al.	2008		provide an extensive review of the scheduling literature on models with setup (costs)	Scheduling	optimal schedules
16	Ruiz et al.	2008	gap between the theory and the practice	minimizing sequence-dependent setup times, maximizing machine eligibility	Mixed integer modelization and Heuristics	optimal schedules

Table 3.1 (continued) : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
17	Omar et al.	2010	hybrid flow shop scheduling problem	minimizing sequence-dependent setup times, maximizing machine eligibility in the electronic sector	MIP	
18	Georgiadis et al.	2005	efficient use of resources, tasks and time	minimization of total operating costs and maximizing customer satisfaction	MIP	optimal schedules with a full customer satisfaction at minimum costs
19	Chen et al.	2007	meet customer due dates with capacity constraint and lead times	maximize machine utilization while minimizing tardiness and earliness penalties of orders	MIP	optimal schedules
20	Sawik, T.	2000	scheduling of a flexible flow line with blocking	determine a production schedule for all products so as to complete the products in a minimum time.	MIP	optimal blocking schedules
21	Harjunkoski et al.	2002	multi-stage scheduling	due date and cost minimization	MILP and Constraint Programming	optimal solution with efficient schedules
22	Prasad et al.	2008	determining production batches, assigning batches to units and sequencing batches assigned to each unit	minimization of earliness, lateness and production cost, while maximization of profit	MILP	balanced production schedule

Table 3.1 (continued) : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
23	Kopanos et al.	2010	scheduling problems in multiproduct multistage batch plants	minimizing order due dates, processing times, sequence-dependent changeover times, unit-dependent setup times and operating cost	MIP	feasible and good solutions in relatively short time
24	Mendez et al.	2001	multi-stage flow shop scheduling problem in batch facilities	minimization of the total order earliness, i.e. the elapsed time between the order completion time and the due date for any order	MIP	The optimal schedule
25	Lasserre, J. B	1992	a planning problem with a fixed sequence of products on the machines, and a job-shop scheduling problem for a fixed choice of the production plan	integrated job-shop planning and scheduling	Scheduling	feasible production plans and schedules
26	Li et al.	2010	production planning and scheduling integration problem	minimizing inventory cost, backorder cost, and production cost	Augmented Lagrangian method	effective in solving the large integration problem and generating a feasible solution.
27	Maravelias et al.	2009	integration of medium-term production planning and short-term scheduling	fulfill customer demand at minimum total (i.e. production + inventory) cost.	MIP and Scheduling	effective in solving the large integration problem and generating a feasible solution.
28	Bhatnagar et al.	2011	coordinating aggregate planning decisions and short-term scheduling decisions	cost minimization	MIP and Scheduling	cost improvements over a wide range of operating scenarios

Table 3.1 (continued) : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
29	Xue et al.	2011	aggregate production planning with sequence-dependent family setup times	minimize the total relevant costs along with minimizing production sequence of product families	Aggregate Production Planning (APP) and Hierarchical Production Planning (HPP)	reason- able and feasible production plans with lower costs
30	Riane et al.	2001	production planning and scheduling integration problem	find a good schedule which generates a lower inventory level, a high plant efficiency	Linear Programming and scheduling	feasible and optimal schedule after determining quantities in each period
31	Jung et al.	2004	Demand uncertainty in the supply chain usually increases the variance of profits or costs to the company.To hedge against demand uncertainty, safety stock levels are commonly introduced.	Determining the safety stock level to use to meet the desired level of customer satisfaction	Simulation-based optimization approach	Safety stock level
32	Zhang et al.	2011	The complexity the production planning issue by considering the bill of materials and the trade-offs between inventories, production costs and customer service level.	Bıild an integrated solution framework	Scatter Evolutionary Algorithm, Fuzzy Programming, and Stochastic chance-constrained programming	The model is effective in developing robust production plans under various market conditions.

Table 3.1 (continued) : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
33	Fildes et al.	2011		develops a framework for examining the effect of demand uncertainty and forecast error on unit costs and customer service levels in the supply chain		the best lot sizing rules for the deterministic situation are the worst whenever there is uncertainty in demand. Unit costs for a given service level increase exponentially as the uncertainty in the demand data increases.
34	Croston, J. D.	1972	intermittent demands almost always produce inappropriate stock levels. Demand for constant quantities at fixed intervals may generate stock levels of up to double the quantity really needed.	Forecasting and Stock Control for Intermittent Demands		
35	Galasso et al.	2008		to satisfy the customer demand while respecting the internal constraints of the production unit and those of its supply chain partners	mixed-integer linear programming model	
36	Mirzapour Al-E-Hashem et al.	2011	multiple suppliers, manufacturers, and customers, addressing a multi-site, multi-period, multi-product aggregate production planning (APP) problem under uncertainty	to minimize production, hiring, firing and training, raw material and end product inventory holding, transportation and shortage cost	Robust multi-objective optimization;	a promising approach to fulfilling an efficient production planning in a supply chain

Table 3.1 (continued) : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
37	Gupta et al.	2000	the framework of mid-term, multisite supply chain planning under demand uncertainty to safeguard against inventory depletion at the production sites and excessive shortage at the customer	the trade-off between customer demand satisfaction (CDS) and production costs	constraint programming approach in conjunction with a two-stage stochastic programming methodology	significant improvement in guaranteed service levels can be obtained for a small increase in the total cost.
38	Leung et al.	2007	the multi-site production planning problem subject to production import/export quotas imposed by regulatory requirements, the use of manufacturing factories with regard to customers' preferences, as well as production capacity, workforce level, storage space	solve multi-site production planning problem with uncertainty data, in which the total costs consisting of production cost, labor cost, inventory cost, and workforce changing cost are minimized	Robust optimization; Stochastic programming	the proposed model is more practical for dealing with uncertain economic scenarios
39	Chen et al.	2014	the inventory of a multilevel distribution network with intermittent lead time extension resulting from disruptive transportation infrastructure damage because of regional weather and non-stationary demands.	reduce both inventory and stock out scenarios	hierarchical decomposition methodology	The forecasting accuracy can be improved; The service level can be guaranteed

Table 3.1 (continued) : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
40	Jiang et al.	2016	the effects of the correlation of intermittent materials on forecasting and stock control		Syntetos-Boylan Approximation	autocorrelation of demand, demand interval, and cross-correlation between demand and demand interval have significant effects on forecasting accuracy and inventory level
41	Altay et al.	2012		the effects of three different types of correlation on forecasting and stock control of intermittent demand items	Correlation; Forecasting	correlation in intermittent demand does play a role in forecast quality and stock control performance
42	Kazemi Zanjani et al.	2010	Robust production planning in a manufacturing environment with random yield		Robust optimization; Stochastic programming	the significance of using robust optimization in generating more robust production plans in the uncertain environments compared with stochastic programming
43	Silva et al.	2009	Successful supply chain management requires a cooperative integration between all the partners in the network.	introduces a new supply chain management technique	Ant colony optimization; Distributed optimization	ant colony optimization allows the exchange of information between different optimization problems by means of a pheromone matrix and it is more efficient than a simple decentralized methodology for different instances of a supply chain

Table 3.1 (continued) : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
44	Gupta et al.	2003	Overview past studies	incorporating demand uncertainty in the midterm planning of multisite supply chains	Stochastic optimization	The proposed model provides an effective tool for evaluating and actively managing the exposure of an enterprises assets to market uncertainties
45	Chen et al.	2004	uncertain multi-echelon supply chain network	to simultaneously maximize participants' expected profit, average safe inventory levels, average customer service	Fuzzy optimization; Mixed-integer nonlinear programming	maximum satisfaction of demands in each period
46	Tratar, Liljana Ferbar	2010	increasing efficiency and improving customer service level	reduce the total cost	HoltWinter's method; Optimization	the average costs can always be reduced by joint optimization
47	Faria et al.	2006	The timely production and distribution of rapidly perishable goods is a complex combinatorial optimization problem. The problem involves several tightly interrelated scheduling and routing problems that have to be solved considering a trade-off between production and delivery costs.	The management methodology consists of allowing each system to exchange information concerning intermediate optimization results through pheromone matrices	Ant Colony optimization; Hybrid methods; Perishabl; Combinatorial optimization; Parallel algorithms; Constrained optimization	the proposed coordination mechanism improves the supply chain performance when compared to another management approach, where both problems are optimized using hybrid methods combining meta-heuristics with constructive heuristics

Table 3.1 (continued) : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
48	Lasschuit et al.	2004	Supporting supply chain planning and scheduling decisions in a competitive area where planning and scheduling are resource-intensive, complex, rolling processes	To minimize transport costs, fixed costs, stock-holding costs	Mixed-integer non-linear programming;	improvement in strategic decision taking the process
49	Nikolopoulou et al.	2012	ascertain the daily production target profiles for each production facility and, product shipment profiles from production facilities to markets	To minimize production cost, transportation cost, inventory holding and shortage costs, subject to capacity and inventory balance constraints	hybrid simulation optimization (MILP; simulation-based optimization)	efficient solution to the operational/tactical level of the supply chain management
50	Arcelus et al.	2012	the conflicting goals of maximizing the expected profit and the probability of exceeding it	To maximize the probability of achieving the expected profit	Bicriteria optimization	the ordering and pricing decisions under demand uncertainty are impacted by the demand
51	Petropoulos et al.	2015	Intermittent demand is characterized by infrequent demand arrivals, where many periods have zero demand, coupled with varied demand sizes. The dual source of variation renders forecasting for intermittent demand a very challenging task.	explores the efficiency of forecast combinations in the intermittent demand context	Croston's method and Syntetos-Boylan Approximation	appropriate combinations lead to improved forecasting performance over single methods, as well as simplifying the forecasting process by limiting the need for manual selection of methods or hyper-parameters of good performing benchmarks.

Table 3.1 (continued) : Literature review.

No	Reference	Year	Problem	Objective	Optimization Method	Outcome
52	Rajopadhye et al.	2001	forecast the uncertain demand for rooms at a hotel for each arrival day	maximize revenue by making decisions regarding when to make rooms available for customers and at what price	the Holt-Winters method	management expertise has to implement into to forecast algorithms
53	Sousa et al.	2008	allocation of too many products/customers to the same resource and idle periods in the planning of the bottleneck resources, preventing the whole system from operating at its maximum capacity	optimize the production and distribution plan considering a time horizon of 1 year, providing a decision support tool for long-term investments and strategies; test the accuracy of the derived design and plan	Enterprise optimisation	An analytical methodology should be developed to use the information gathered in the second step to improve the supply chain design and plan by enforcing a more distributed allocation of products/customers to the available resources in each time period
54	Kourentzes, Nikolaos	2014	Intermittent demand time series involve items that are requested infrequently, resulting in sporadic demand. But a consistent and valid optimization methodology is lacking	maximizing the accuracy of demands	Croston’s method	The proposed metrics are found to not only perform best but also provide consistent parameters with the literature, in contrast to conventional metrics. This work validates that employing different parameters for smoothing the non-zero demand and the inter-demand intervals of Croston’s method and its variants is beneficial

4. MATHEMATICAL MODEL

The primary goals of this model are as follows:

- To increase on-time delivery adherence to promised date setting and to minimize postponements
- To manage customer and order priority
- To minimize stock levels while improving service level of Central European Warehouse

4.1 Aggregate Planning Model

This model aims to find the optimal allocation of remaining capacities to product groups. A product group is defined as the products which have same specifications like size, material etc. and could be produced together.

At this level of planning a high-level overview over the capacities based on product groups are considered and the main goal is to meet the forecasted requirements while considering both capacity availabilities and at the same time production costs/preferences.

In the Aggregate Planning Model, the preferred time bucket is a month and forecasts are generated on a monthly basis. The primary purpose is to allocate monthly production process capacities to forecasts for each product group and try to avoid allocating capacities to those that do not have open forecasted quantities. Open forecasted quantity is described as the forecast for that month minus all the open orders under that product group.

4.1.1 Decision variables and parameters

Indices

m : Product groups, $m \in M$, M:{1,2,…,m^{max}}

t : Periods, $t \in T$, T:{1,2,…,t^{max}} . In this model time bucket is a month.

p : Production process, $p \in P$, P:{1,2,…,p^{max}}

Parameters

$D_{m,t}$: Open forecasted quantity for product group *m* in period *t*.

$c_{p,t}$: Total available production capacity of process *p* in period *t*. The capacity is expressed in time (seconds).

$s_{m,p}$: Unit operation time for product group *m* in process *p*.

K_m : The set of material codes with product group *m.*

$s_{k,p}$: The unit operation time of item *k* in production process *p*

$s_{m,p} = \max\{s_{k,p}; k \in K_m\}$

$w_{m,p}$: Penalty cost for assigning product group *m* to production process *p*. It is used to ensure that prioritized process is being selected.

h_m : Monthly stock keeping cost for product group *m.*

b_m : Backorder penalty cost for not satisfying product group *m*'s forecast on its month but one month later.

4.1.1.1 Decision variables

$X_{m,p,t}$: Amount of product group *m* assigned to process *p* in period *t*.

$I_{m,t}$: Inventory built up for product group *m* at the end of period *t*.

$B_{m,t}$: Backorder level for product group *m* at the end of period *t*.

4.1.2 Constraints

Capacity constraint is to indicate that total production in process *p* during period *t* cannot exceed the total available production capacity of process *p* in period *t.*

For all *p* and *t*;

$$\sum_m s_{m,p} X_{m,p,t} \le c_{p,t} \qquad (4.1)$$

Inventory balance constraint is used to calculate total inventory and backorder levels for each product group at the end of each period.

For all *m* and *t*;

$$I_{m,t+1} - I_{m,t} + B_{m,t} + D_{m,t} - \sum_{p} X_{m,p,t} = 0 \qquad (4.2)$$

4.1.3 Objective function

Our goal is to minimize the total cost associated with the Aggregate Plan.
Production and penalty cost for process priority is;

$$\sum_{k}\sum_{p} w_{m,\ p} \sum_{t} X_{m,\ p,\ t} \qquad (4.3)$$

Monthly stock keeping cost is;

$$h_{m} \sum_{t} I_{\mathrm{m},\ t} \qquad (4.4)$$

Backorder cost is;

$$b_{m} \sum_{i} B_{m,\ t} \qquad (4.5)$$

Total cost is;

$$Min\ Z = \sum_{k}\sum_{p} w_{m,\ p} \sum_{t} X_{m,\ p,\ t} + h_{m} \sum_{t} I_{\mathrm{m},\ t} + b_{m} \sum_{i} B_{m,\ t} \qquad (4.6)$$

4.2 Daily Capacity Plan Model

Daily capacity plan model is a Mixed Integer Programming (MIP) aims to find production lot sizes for the pioneering level codes considering setup preferences, minimum lot sizes and scrap rates at the pioneering production lines. The pioneering productions lines are the bottleneck and the main constrainted resources in the production sequence.

This model uses the outputs of Aggregate Planning Model for product groups in monthly periods in order to find the optimum production lot sizes for the products in each group.

4.2.1 Decision variables and parameters

Indices

k : Pioneering process outcomes., $k \in K$, K:{1,2,…,k^{max}}

m : Product groups, $m \in M$, M:{1,2,…,m^{max}}

p : Production process, $p \in P$, P:{1,2,…,p^{max}}

t : Periods, $t \in T$, T:{1,2,…,t^{max}}

o: List of all open customer orders, $o \in O$, O:{1,2,…,o^{max}}

$O_k \subseteq O$: List of all open orders for item *k*.

Parameters

β_k : Minimum lot size for item *k*.

$c_{p,t}$: Total available capacity of process *p* in period *t* expressed in time units (seconds).

q_o : Total open quantity of order *o*.

$d_{o,p} = \left\lceil \frac{q_o}{s_{k,p}} \right\rceil$: Total duration (in terms of a number of days) for order *o* in process *p*, where order *o* is for item *k*.

$s_{k,p}$: Unit operation time (seconds) of material *k* in process *p*.

r_o : The requested period of order *o*.

$w_{k,p}$: Unit cost (penalty) of producing item *k* in process *p*.

$v_o^{(1)}$: Penalty cost for tardiness for order *o*.

$v_o^{(2)}$: Penalty cost for earliness for order *o*.

$v_k^{(3)}$: Penalty cost for quantity produced to stock for item *k*.

4.2.1.1 Decision variables

$U_{o,p,t} = \{0,1\}$: it is 1 if order *o* in period *t*, is started to be processed in process *p* and it is 0 otherwise

$X_{o,p,t} = \{0,1\}$: It is 1 if order *o* in period *t* is assigned to process *p*, and it is 0 otherwise

f_o : Planned finish period for order *o*

$Y_{o,p,t} \geq 0$: Quantity of order *o*, allocated to resource *p* in period *t*. This decision variable is needed especially for large orders with an open quantity greater than the total daily capacity of its process.

$Q_{k,p,t} \geq 0$: Make-to-stock quantity of item *k* from process *p* in period *t*.

$\theta_o \geq 0$: Tardiness of order *o*. That is if $f_o > r_o$, then $\theta_o = f_o - r_o$, else $\theta_o = 0$

ϑ_o: Earliness of order *o*. That is if $f_o < r_o$, then $\vartheta_o = r_o - f_o$, else $\vartheta_o = 0$.

4.2.2 Constraints

Order planning constraint is to ensure that all orders are placed on the capacity plan, and there is exactly one process and one starting period planned for each order.

For all *o*, *p* and *t*;

$$\sum_p \sum_t U_{o,p,t} = 1 \tag{4.7}$$

Production flow constraint is used to ensure that once the production for an order is started to be produced in period *t* it will continue during the calculated duration of the order.

For all *o*, *p* and *t*;

$$X_{o,p,t} \geq U_{o,p,t} \tag{4.8}$$

Production quantity constraint is used to ensure that if an order is not planned to be processed by process *p* in period *t*, then the corresponding production quantity is zero.

For all *o*, *p* and *t*;

$$Y_{o,p,t} \leq q_o X_{o,p,t} \tag{4.9}$$

Capacity constraint is used to ensure that all production for a process *p* in period *t* obey the capacity limitation of that process in the period.

For all *p* and *t*;

$$\sum_k s_{k,p} \sum_{o \in O_k} Y_{o,p,t} + \sum_k s_{k,p} Q_{k,p,t} \leq c_{p,t} \tag{4.10}$$

Order satisfaction constraint is used to ensure that total production quantity for an order satisfies its open quantity.

For all *o*;

$$\sum_{p}\sum_{t} Y_{o,p,t} \geq q_o \tag{4.11}$$

It is assumed that the minimum lot size can never be greater than the production capacity per period (day) for each item to be produced in pioneering processes.

For all i, *p* and *t*;

$$\sum_{o \in O_k} Y_{o,p,t} + Q_{k,p,t} - \beta_k \sum_{o \in O_k} X_{o,p,t} \geq 0 \tag{4.12}$$

Tardiness / Earliness constraint is used to ensure that if the planned finish time of order *o* is later than its promised date (order is tardy) then, the tardiness of the order is $\theta_o = f_o - r$ and the earliness of the order is zero.

For all *k*, *p*, and *t*;

$$tU_{o,p,t} + d_{o,p} - \theta_o + \vartheta_o \leq r_o \tag{4.13}$$

4.2.3 Objective function

Our goal is to minimize total production costs and to minimize the difference between job finalizing date and requested dates.

Production cost is;

$$\sum_{k}\sum_{p} w_{k,p} \tag{4.14}$$

Penalty cost is;

$$\sum_{o} v_o^{(1)} \theta_o + \sum_{o} v_o^{(2)} \vartheta_o + \sum_{k} v_k^{(3)} \sum_{p}\sum_{t} Q_{k,p,t} \tag{4.15}$$

Capacity allocation cost is;

$$\sum_{o \in O_k}\sum_{t} Y_{o,p,t} \tag{4.16}$$

Minimize

$$Z=\sum_{k}\sum_{p}w_{k,p}\sum_{o\in O_k}\sum_{t}Y_{o,p,t}+\sum_{o}v_o^{(1)}\theta_o+\sum_{o}v_o^{(2)}\vartheta_o+\sum_{k}v_k^{(3)}\sum_{p}\sum_{t}Q_{k,p,t} \quad (4.17)$$

4.3 Central European Warehouse Order Planning Model

Central European Warehouse is operating according to make-to-stock strategy with some target response times (service levels) towards its customers. The main supply sources are the production facilities in Germany and Turkey. For the parts that are to be requested from Turkey, in order to provide reliable future estimates to Turkish plant capacity allocations, the replenishment orders of Central European Warehouse is estimated by the Model. The model run for each material separately.

4.3.1 Decision variables and parameters

Indices

t : Periods, $t \in T$, T:$\{1,2,\ldots,t^{max}\}$. The minimum time bucket for the Central European Warehouse is a month.

Parameters

L : Replenishment lead-time.

$\bar{Q}(t)$: Total quantity, among the currently open orders, scheduled for receipt at the start of period *t*.

$I^{+}(0)$: Current on-hand inventory at the warehouse.

$I^{-}(0)$: Total quantity of customer orders currently waiting to be satisfied.

$D(t)$: Demand forecast for period *t*.

ss : Safety stock level.

h_f : Penalty cost for holding finished goods inventory.

M^{+} : A very big number.

4.3.1.1 Decision variables

$Q(t)$ = The quantity of the order to be released at the start of period *t*.

$I(t)$ = Planned net inventory level at the start of period *t*.

$S^-(t)$ = Net inventory level below the safety stock at the start of period *t*.

$S^+(t)$ = Net inventory level over the safety stock at the start of period *t*.

4.3.2 Demand balancing constraints

Beginning period inventory balance constraint is defined as;

$$I(1) - I^+(0) - \overline{Q}(0) + I^-(0) + D(0) = 0 \tag{4.18}$$

Inventory balance constraint in period *t* is defined as;

$$I(t+1) - I(t) - \overline{Q}(t) + D(t) = 0 \tag{4.19}$$

Replenishment constraint in period *t* is defined as;

$$I(t+1) - I(t) - Q(t-L) - \overline{Q}(t) + D(t) = 0 \tag{4.20}$$

Safety stock constraint in period *t* is defined as;

$$S^+(t) - S^-(t) - I(t) + ss = 0 \tag{4.21}$$

4.3.3 Objective function

The main goal is to keep as less finished goods stock as possible and at the same time satisfy all orders and demand forecasts while adhering to safety stock and lead time limitations. The model will be as follows.

$$Minimize\ Z = h_f \sum_t I^+(t) + M^+ \sum_t S^-(t) \tag{4.22}$$

5. IMPLEMENTATION

The reservation performance data before the implementation is used to determine lateness, earliness and demand fulfillment from stock and three notions are defined:

- An order is late if Last Reservation Date > Last Promised Date + 7
- An order is early if Last Promised Data > Last Reservation Date + 14
- An order is satisfied by stock if Order Date + 3 > Last Reservation Date
- The promised time of an order is the time between its creation date and its first promised date.
- The reserve time of an order is the time between its creation date and its reservation date.

The customers are categorized into three segments by their customer priorities:

- X
- Y
- Z

According to data, the results are defined in the following table.

Table 5.1 : Performance Data Results Before Implementation.

Customer Priority	Total Production (m^2)	Avg Weighted Promise Time (days)	Avg Weighted Reserve Time (days)	Late Orders (%)	Early Orders (%)	Satisfied From Stock (%)
X	5.8 Million	36 - 52	36 - 51	23 - 32	13 - 18	28
Y	22 Million	90 - 106	78 - 89	19 - 21	33 - 38	12
Z	3.6 Million	57 - 66	53 - 60	23 - 26	23 - 24	12

Mathematical models are developed and implemented in ICRON [55] modeling environment. ICRON [55], which is an object-oriented modeling environment, has an integrated visual algorithm component that makes model development progress easier for every kind of practices. By its cutting-edge, proprietary graphical modeling framework so called GSAMS, nodes are connected to each other as in flow charts to construct algorithms for any kind of decision-making problem. A node represents a specialized function, which returns a predefined output and designed to make life easy for modelers who have limited computer science background.

ICRON [55] has a modular structure is leveraged by XML and C++. The environment enables development of hybrid and sophisticated decision support systems by connecting distributed computing, mathematical programming, heuristic approach, high integration capability with ERP databases such as SAP, Oracle, AXAPTA and MS Office components and web service support.

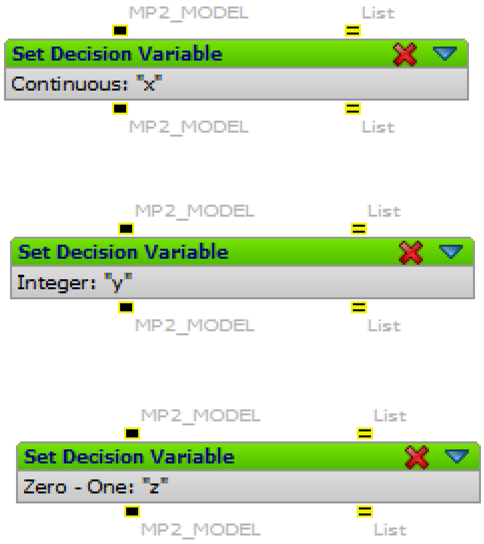
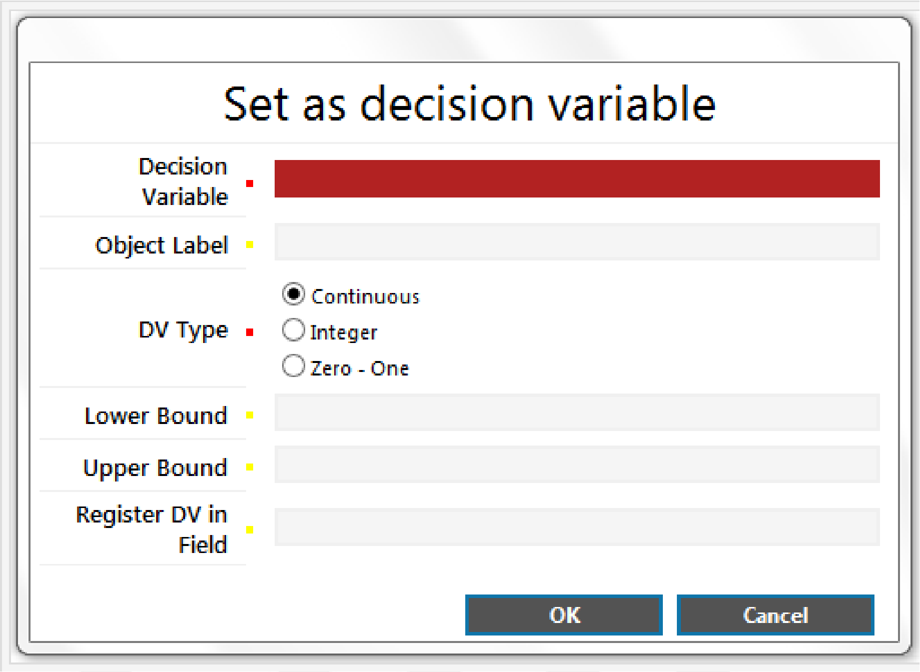


Figure 5.1 : Defining Decision Variables

Set Decision Variable node sets a field of an object as a decision variable according to the user parameters of the node. The node receives a MP2_MODEL object and a list of objects. For each object in List input link point, the field specified in "Decision Variable" user parameter is identified as a decision variable of the MP2_MODEL object. Specifically, an MP2_DecisionVariable object is created for each object in the list, and is added to MP2_MODEL's DecisionVariables list.

When you double click on the node during design time, the form that is shown in Figure 5.2 appears.



DV Type
● Continuous
○ Integer
○ Zero - One

Figure 5.2 : Setting Decision Variables

Decision Variable : The field of each object in List to be designated as a decision variable. The selected field must be an assignable field, whose return type is Number.

Object Label : The label for the decision variable, which will be used in optimization log files and screen output. The entered expression must evaluate to a String. The automatically generated index of the corresponding MP2_DecisionVariable will be appended to the label by ICRON so that each decision variable has a unique label.

Decision Variable Type : Type of decision variable. Possible options are;

Continuous: represents a continuous decision variable

Integer: represents an integer decision variable, whose value must be integral

Zero - one: represents a binary decision variable, whose value must be either 0 or 1

Lower Bound : If an expression is entered, the lower bound of the created decision variable is set as the evaluated numerical value of the expression. Otherwise, the lower bound is set to 0 by default.

Upper Bound : If an expression is entered, the upper bound of the created decision variable is set as the evaluated numerical value of the expression. Otherwise, the upper bound is set to MP2_MODEL.Infinity if DV Type is chosen as Real or Integer, and to 1 if Decision Variable Type is chosen as Zero-one.

Register Decision Variable in Field : If an expression is entered, each created MP2_DecisionVariable will be registered to the relation defined by the expression.

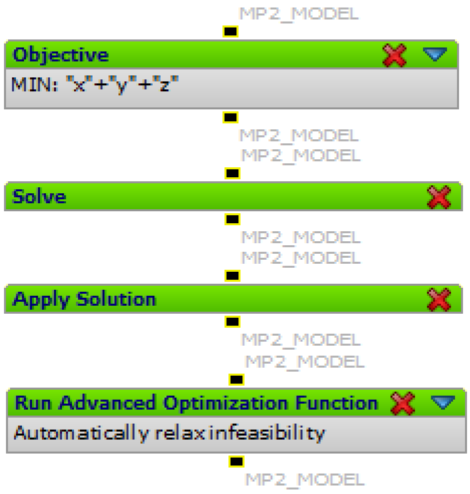
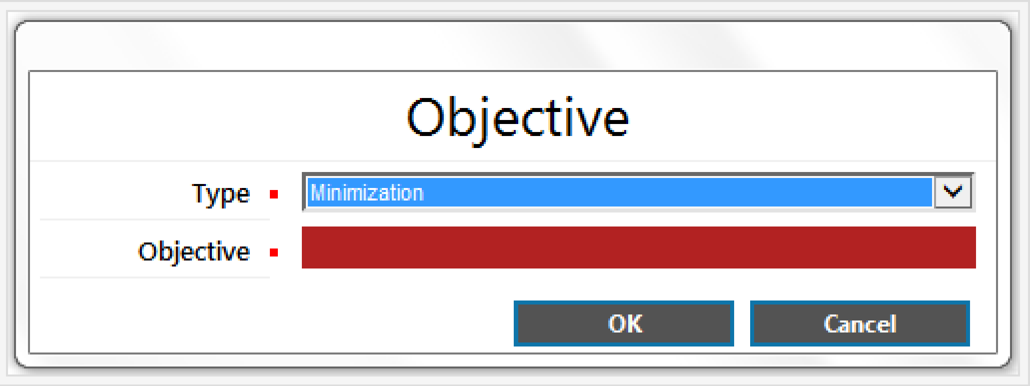


Figure 5.3 : Objective Function and Solution

The minimization or maximization selection is defined with the objective function node. Objective node sets the objective function of the optimization problem represented by the MP2_MODEL object received via the fixed input link point. When you double click on the node during design time, the following form appears:


Objective

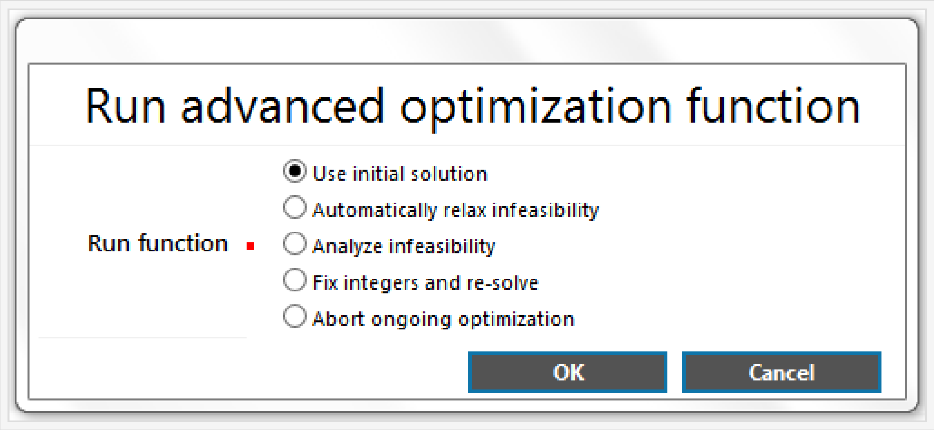
Type: Minimization

Objective:

Figure 5.4 : Setting Objective

With the "Solve" command, the resulting pattern is transferred to the CPLEX decoder. During this transfer, relationships created over objects are transformed into equations. If an authentic solution is obtained, the decision variables determined by the "Apply solution" command are associated with the objects. Apply Solution assigns the current values of all MP2_DecisionVariable objects in MP2_MODEL to the corresponding fields of their related objects. The node does not contain any user parameters, and it assumes that a feasible solution of the optimization model is readily available.

Run Advanced Optimization Function has various options listed as user parameters for executing advanced functionality of ICRON's optimization engine and the underlying solver. When you double click on the node during design time, the following form appears:



Run advanced optimization function

Run function ▪
● Use initial solution
○ Automatically relax infeasibility
○ Analyze infeasibility
○ Fix integers and re-solve
○ Abort ongoing optimization

Figure 5.5 : Setting Advanced Optimization Function

The advanced optimization function to be executed. Possible options are:

Use initial solution: Instructs ICRON to extract initial values for integer or zero-one decision variables from the current values of the corresponding objects and fields, and pass these values to the selected solver for a possible initial solution. If the current value of an integer or zero-one decision variable is fractional, then ICRON skips the variable while passing initial values to the solver.

Automatically relax infeasibility: If the current MP2_MODEL is found to be infeasible by a previous call to Solve, this option automatically relaxes some variable bounds and constraint right-hand-side values to regain feasibility.

Analyze infeasibility: If the current MP2_MODEL is found to be infeasible by a previous call to Solve, this option automatically analyzes the infeasibility to calculate a minimal infeasible subsystem of the existing constraints and decision variables.

Fix integers and re-solve: If the current MP2_MODEL contains some integer or zero-one decision variables and its solution was terminated before optimality was proven, this option fixes the integer and zero-one variables at their current values and re-solves the remaining linear programming problem in order to improve solution quality.

Abort ongoing optimization: This option instructs ICRON and the selected solver to stop the solution process of MP2_MODEL.

5.1 Model Outputs

After model implementation, it is expected a decrease in early and late orders percentage with an increase in satisfaction from stocks percentage as soon as possible. The most important contribution of this study is that the production plan is even more visible for the planners.

While the model was being developed, real life problems, as well as studies in the literature, were leading. For this reason, it is expected that the benefits of the model will be seen in a short time also in the operation of the implementation.

It is aimed that this work will be a guide for demand-driven producers. It is considered that a solution to the daily planning problem will be useful for dissemination in demand and customer oriented other companies.

At the same time, it will be possible to prevent wrong planning with the whole system being visible (stock, order, capacity etc.). This subject can be exemplified by solution methods in real life. For example, in the ceramic tile sector, when machinery is not planned properly with the right production sequence and quantity, idle inventories increase, customer demands are further delayed, and eventually, orders are canceled.

6. CONCLUSIONS

In this study, an integrated planning system was established at one of the largest ceramic tile manufacturing company in Turkey. The company performs in a multi-facility production environment. As the nature of the tile industry, the environment is highly competitive and, hence, highly dynamic. The Supply Chain department's main concern is propagating the best production plan in the long and short term to be able to compete in this dynamic environment.

We divided the planning problem of the company into two phases: aggregate capacity planning and daily capacity planning. In aggregate capacity planning, the purpose is to figure out monthly production and capacity allocation requirements given the monthly forecasts created by the sales department. In the daily capacity planning phase, the daily detailed production plan is developed. That is, the quantity, beginning and end times of production batches for finished and semi-finished products are generated as a result of the daily capacity planning phase.

In aggregate capacity planning, the problem is designed as a linear programming (LP) model, which is very much alike to classical aggregate production planning problem. Daily capacity planning model is determined in two steps. In the first step, a mixed integer programming (MIP) model, i.e. batch sizing model, runs which is very much alike to capacity planning model. Here, the model has smaller time buckets and shorter planning horizon. After the production batches are decided in MIP model, they are scheduled using a heuristic procedure.

All two modules are implemented using the development environment provided by ICRON Supply Chain Optimization System [55]. The developed planning system operates combined with other systems of the company such as SAP etc. Data flows connected with planning activities are realized among those systems via ICRON. The planning system also supports interactions of planning department with other departments such as sales department and shop floor management.

A number of advantages of using the planning system such as enhanced customer service level, improved responsiveness, improved due dates etc. is detected.

Optimization of inventory flow effected in an enhanced product mix, consequently, customer service levels are dramatically increased. The irrelevant inventory based on an imperfect estimation of production requirements are minimized. Before the planning system is implemented, average lateness was 27%, earliness was 25% and demand fulfillment from stock was 15%. After implementation, improvements in lateness, earliness and customer satisfaction are expected as soon as possible.

With the planning system, planners can also see the bottlenecks in the capacity. So, they can control productions such that they do not face any loss of sales. They can also lead the sales department by revising forecasts.

The operating environment of the company is highly competitive. It is not unusual to face a very extreme marketing progress by one of the competitors. Usage of the planning system enhanced the awareness of the company to take a correct position against such confusions on the estimated state of the market conditions. The main intention is that the planning system driven the daily operations of planners. Integration of planning system with SAP allows planners to have an analysis of shop floor so that they can discover errors and modify them quickly.

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