ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A DECISION MODEL FOR CUSTOMER ORDER PRIORITIZATION AND FACILITY LAYOUT DESIGN, A CASE STUDY FOR STRUCTURAL STEEL PRODUCTION IN CONSTRUCTION INDUSTRY

Ph.D. THESIS

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

MÜŞTERİ SİPARİŞİ ÖNCELİKLENDİRİLMESİ VE TESİS YERLEŞİM TASARIMI İÇİN KARAR MODELİ, İNŞAAT SEKTÖRÜNDE YAPISAL ÇELİK ÜRETİMİ İÇİN BİR UYGULAMA

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ŞUBAT 2018

Burcu Nalbantoğlu, a Ph.D. student of ITU Graduate School of Science Engineering and Technology student ID 507112101, successfully defended the thesis/dissertation entitled “A DECISION MODEL FOR CUSTOMER ORDER PRIORITIZATION AND FACILITY LAYOUT DESIGN, A CASE STUDY FOR STRUCTURAL STEEL PRODUCTION IN CONSTRUCTION INDUSTRY”, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Teslim Tarihi : 26 Şubat 2018
Savunma Tarihi : 05 Şubat 2018

To my spouse and parents,

FOREWORD

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Burcu NALBANTOĞLU
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ABBREVIATIONS

AGV : Automated Guided Vehicle
AHP : Analytic Hierarchy Process
AMPL : A Modeling Language for Mathematical Programming
ANP : Analytic Network Process
COUENNE : Convex Over and Under ENvelopes for Nonlinear Estimation
DA : Decision Analyst
DEMATEL : The Decision-Making Trial and Evaluation Laboratory
DM : Decision Maker
ELECTRE : Elimination et choix traduisant la réalité
FCM : Fuzzy Cognitive Map
MCDM : Multi Criteria Decision Making
MAG : Metal Active Gas Welding
MIP : Mixed Integer Programming
MINLP : Mixed Integer Non-linear Programming
MMA : Manual Metal Arc Welding
MTS : Make to Stock
MTO : Make to Order
NDT : Non-destructive Testing
PCO : Potential Customer Orders
PROMETHEE: Preference Ranking Organization Method for Enrichment Evaluation
QAP : Quadratic Assignment Problems
SAW : Mixed Integer Non-linear Programming
SMARTS : Submerged Arc Welding
SME : Small Medium Enterprise
SRO : Short Range Outlook
TOPSIS : The Technique for Order Preference by Similarity to Ideal Solution
TQM : Total Quality Management

SYMBOLS

$\mathbf{f_{ik}}$	: The flow between workstations i and k
$\mathbf{d_{jl}}$	: The distance between locations j and l
$\mathbf{c_{ij}}$	: The cost of placing workstation i at location j
$\mathbf{x_{ij}}$	: Binary variable: 1 if workstation i is assigned to location j, otherwise, 0
$\mathbf{(x_i,y_i)}$	: The coordinate of center point of the workstation
$\mathbf{(x_{it},y_{it})}$	: The coordinate of the top-left of the workstation
$\mathbf{(x_{ib},y_{ib})}$	: The coordinate of the bottom-right of the workstation
$\mathbf{O_{ij}}$	: The overlap area between two workstations
$\mathbf{B_x}$	: The shop flow length (x-axis)
$\mathbf{B_y}$	: The shop flow width (y-axis)
$\mathbf{L_i}$	: The length of workstation i
$\mathbf{W_i}$	: The width of workstation i
$\mathbf{k_i}$	: The out-going flow of workstation i
$\mathbf{n_i}$	: The capacity of workstation i
c	: The cost to move one unit per one distance unit from workstation i to workstation j
$\mathbf{x_i}$	: The x-coordinate of the left (west) side of workstation i
$\mathbf{y_i}$	: The y-coordinate of the bottom (south) side of workstation i
$\mathbf{f_{i,j}}$	: The flow frequency from workstation i to workstation j
$\mathbf{zx_{i,j}}$	: Binary variable: 1 if workstation i positions strictly to the east of workstation j, Otherwise 0
$\mathbf{zy_{i,j}}$	: Binary variable: 1 if workstation i positions strictly to the north of workstation j, Otherwise 0
$\mathbf{d^x_{i,j}}, \mathbf{d^y_{i,j}}$	: Nonnegative variables

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A DECISION MODEL FOR CUSTOMER ORDER PRIORITIZATION AND FACILITY LAYOUT DESIGN, A CASE STUDY FOR STRUCTURAL STEEL PRODUCTION IN CONSTRUCTION INDUSTRY

SUMMARY

The competitiveness of world market is constantly increasing for structural steel manufacturing companies. The design and manufacturing capacities are limited for these companies. As a result, first these manufacturing companies should select the most suitable project(s) among the potential projects and then they have to optimize their manufacturing layout system for selected project(s) to gain more profit. When these targets are not reached; time, money and opportunity losses occur for these manufacturing companies. Therefore, in this study, useful tools for achieving these targets are stated.

This study has made a difference by providing real life industrial approaches together with academic algorithms. Also, companies generally do not want to publish their in-house data in academic studies as a result of their confidentiality principle, but the company that has been considered in this study has also approved the use of related data in the study. In this context, the study presents an insight to other similar studies as a combination of practical industrial knowledge and academic methods.

This study focuses on multi-purpose decision making and optimization in a sequential way; and aims to find a solution to proper order selection and factory layout problems. In the study, it is aimed to develop a decision support model to select the most suitable orders among the alternatives and to create a factory layout design model for these selected orders. The proposed problem solutions are expressed as a case study for a structural steel manufacturer in Turkey.

Customer order prioritization is a very critical and crucial issue for the manufacturing companies as far as their limited capacities are concerned. When the current awarded projects start to cover large portions of the company's design and manufacturing capacities, the company confronts with the decision problem of choosing which customer order next to allocate the remaining scarce capacities properly. In order to make this decision, related criteria are determined based on the literature survey and confirmations of decision makers and then customer orders are evaluated with respect to these criteria. As there are several criteria lacking a basis of comparison and causing confliction, a multi criteria decision-making process is required.

At this study, an Analytic Network Process (ANP) based decision framework was developed by using the criteria to prioritize customer orders under the limited capacities of a structural steel manufacturing company. The decision makers of the company were factory manager, business development manager and technical office manager. Because these decision makers have different opinions, the decision process was very hard. Therefore, ANP, a group decision-making model, was used to take everyone’s opinion into account and to achieve the best possible decision. ANP

model was a guide in selecting among a set of customer orders, which can be regarded as alternatives. These alternatives are evaluated on the basis of several criteria which had different priorities. These criteria were determined as the potential profit rate per unit of time, the compatibility of potential order with the available capacity, the level of potential future order with higher profit, customer credit of future business opportunity, and the negotiability level of production schedule for the order based on the literature review and decision-makers' confirmations. Among them, customer credit of future business opportunity criterion was revealed as the most important one by priority of 35.48%. The other criteria are listed based on priority respectively: the potential profit rate per unit time (26.77%), the negotiability level of production schedule for the order (14.38%), the level of potential future order with higher profit (12.11%), and the compatibility of potential order with the available capacity (11.26%). The prioritizations of customer orders gathered from the study were respectively "administrative building in Gemlik" (21.64%), followed by "shopping center in Sapanca" (20.82%). The subsequent projects were "housing project in Algeria" (15.68%), "factory in Pakistan" (12.68%), "water sports center in Cengelkoy" (11.01%), and "city hall project in Georgia" (10.37%). The least preferred project was "compressor station in Eskisehir" (7.81%). Selection recommendation between these customer orders were made by solving a knapsack problem in which the priorities of the criteria were supposed to be the coefficients of the objective function and there was a constraint which considered company's design and production capacity. This solution was presented to the structural steel manufacturing company's decision makers and they were recommended to choose projects in accordance with the solution which was the first, the second, and the fourth customer orders. DMs chose the orders in accordance with this recommendation.

Facility layout design is also an important component of a manufacturer's overall operations, both in terms of maximizing the effectiveness of the production process and minimizing production cost.

Factory characteristics which are "product variety and volume", "facility shapes and dimensions", "material handling systems", "number of floors in the facility", "backtracking and by passing", "pick-up and drop-off locations" should be taken into account in factory layout design.

Based on the product variety, the facility design can be static or dynamic. The factory layout design for the structural steel company under consideration is static and because the awarded projects are unique for each order, the facility design should be redesigned for each order. The facility layout problem concentrates on finding positions of workstations on the facility floor based on changing product orders such that workstations do not overlap, and the sum of the material handling costs is minimized.

In this study, the workstations require unequal rectangular areas and free orientations, and the layout is generated on the continuous plant floor. In the facility design phase, the complexity of structural steel manufacturing process is taken into consideration, the MINLP mathematical model of the facility layout is described by AMPL software, and the feasible solution is gathered by using Couenne solver for assignment of workstations in locations. If the current factory layout was considered in the production, the total manufacturing cost would be USD1,350,435-. On the other hand, the total production cost of the proposed mathematical model is computed as USD1,072,442-, which is more than 20 percent less than the current location cost. As a result, the solution of the problem is implemented by the company under consideration.

Consequently, this study aims to present an insight to the cooperation of academic studies and industrial problems. Based on the literature review, this is the first study for prioritizing customer orders in a multi-criteria decision-making environment and designing the facility layout sequentially for the manufacturing companies in steel industry. The companies which wish to make the right decision in selecting among the most appropriate order alternatives and in designing their facility in accordance with selected order(s) to minimize handling costs must use techniques that are based on the most critical criteria and constraints, but these techniques will not be used if they cannot be understood readily by managerial decision makers. Although there is no lack of techniques for order selection evaluation and factory layout design, there is a total lack of a framework for organizing these techniques logically in a practicable process. The essence of this thesis is to choose between the orders demands that exceed the companies' capacities and to consider this order selection in facility layout design by using purely real data on structural steel production, which has never been dealt with in the literature.

MÜŞTERİ SİPARİŞİ ÖNCELİKLENDİRİLMESİ VE TESİS YERLEŞİM TASARIMI İÇİN KARAR MODELİ, İNŞAAT SEKTÖRÜNDE YAPISAL ÇELİK ÜRETİMİ İÇİN BİR UYGULAMA

ÖZET

Dünya pazarındaki rekabet, yapısal çelik üretim şirketleri için sürekli artmaktadır. Üretim firmalarının kapasiteleri dizayn ve üretim kapasiteleri bakımından sınırlıdır. Bunların bir sonucu olarak, öncelikle imalat firmaları potansiyel projeler arasından kapasitelerini göz önüne alarak en uygun projeyi / projeleri seçmeli ve daha fazla kâr elde etmek için seçtikleri bu proje / projeler için fabrika yerleşim sistemini optimize etmelidir. Bu hedeflere ulaşılamadığı durumda üretim firmaları zaman, para ve fırsat kayıpları yaşamaktadırlar. Bu sebeple bu çalışmada, bu hedeflere ulaşmak için faydalı olacak araçlar ele alınmaktadır.

Bu çalışma akademik algoritmalarla gerçek endüstriyel yaklaşımların birlikte ele alınmasını sağlayarak bir farklılık yaratmayı sağlamıştır. Ayrıca, genellikle akademik çalışmalarda firmalar kendi verilerinin yayınlanmasını gizlilik prensibi ile istememektedirler, ancak bu çalışmada göze alınan firma ilgili bilgilerin çalışmada kullanılmasına da onay vermiştir. Bu bağlamda, söz konusu çalışma pratik endüstriyel bilgi ile akademik metotların bir kombinasyonu olarak başka benzer çalışmalara bir içgörü sunmaktadır.

Bu çalışma çok amaçlı karar verme ve optimizasyonu ardışık olarak ele alarak uygun sipariş seçimi ve fabrika yerleşimi problemlerine çözüm bulmayı hedeflemektedir. Çalışmada, seçenekler arasında en uygun siparişleri seçmek için bir karar destek modeli geliştirilmesi ve seçilen bu siparişler için bir fabrika yerleşimi tasarım modeli oluşturulması amaçlanmaktadır. Öne sürülen söz konusu problem çözümleri Türkiye'de yapısal çelik alanında faaliyette olan bir üretici üzerinden uygulamalı olarak ifade edilmiştir.

Müşteri sipariş önceliklendirilmesi, imalat şirketleri için sınırlı kapasiteleri göz önüne alındığında çok kritik ve önemli bir konudur. Mevcut durumda kazanılmış olan projeler firmanın dizayn ve üretim kapasitelerinin büyük bölümünü kaplamaya başladığında, firma kalan kapasitesini en doğru şekilde kullanabilmek için bir sonraki sipariş olarak hangi müşterinin siparişinin alması gerektiği konusunda karar vermesi gereken bir problemle karşı karşıya kalmaktadır. Bu kararın verilebilmesi için, ilgili kriterler literatür taraması sonucunda karar vericilerin de onayları alınarak tespit edilmekte ve sonra müşteri siparişleri bu kriterler temel alınarak değerlendirilmektedir. Bir karşılaştırma temelinden yoksun ve çatışmaya neden olan bir çok kriter olduğu için, çok kriterli bir karar verme süreci gerekli olmaktadır.

Bu çalışmada, bir yapısal çelik şirketinin sınırlı kapasiteleri altında müşteri siparişlerine öncelik verme kriterleri kullanılarak bir Analitik Ağ Süreci tabanlı karar modeli oluşturulmuştur. Firmanın karar vericileri fabrika müdürü, iş geliştirme müdürü ve teknik ofis müdürüdür. Karar vericilerin farklı fikirlere sahip olması

nedeniyle, karar süreci çok zor olmaktadır. Bu sebeple, herkesin fikrini dikkate alan ve mümkün olan en iyi karara ulaşmayı sağlayan grup karar verme modeli ANP kullanılmıştır. ANP modeli, alternatifler olarak nitelendirilen müşteri siparişleri seti arasında seçim yapmak için bir rehber olarak kullanılmıştır. Bu alternatifler, farklı öncelikleri olan çeşitli kriterlere göre değerlendirilmiştir. Kriterler, birim zaman başına potansiyel kâr oranı, potansiyel siparişin mevcut kapasite ile uyumluluğu, potansiyel ve daha yüksek kârlı gelebilecek gelecekteki başka sipariş(ler)in düzeyi ve gelecekteki iş fırsatı açısından müşteri kredisi ve iş programının müşteri ile tartışılabilirlik düzeyi şeklindedir. Bunların arasında gelecekteki iş fırsatı açısından müşteri kredisi %35.48'lik öncelikle en önemli kriter olarak ortaya çıkmıştır. Öncelik düzeyi açısından diğer kriterler şu şekilde sıralanmaktadır: birim zaman başına potansiyel kâr oranı (%26.77), iş programının müşteri ile tartışılabilirlik düzeyi (%14.38), potansiyel ve daha yüksek kârlı gelebilecek gelecekteki başka sipariş(ler)in düzeyi (%12,11) ve potansiyel siparişin mevcut kapasite ile uyumluluğu (%11.26). Siparişlerin önceliklendirilmesi sırasıyla “Gemlik idari binası" (% 21.64), ardından "Sapanca alışveriş merkezi" (% 20.82) şeklinde gerçekleşti. Daha sonraki siparişler ise "Cezayir'de konut projesi" (% 15.68), "Pakistan fabrikası" (% 12.68), "Cengelköy'de su sporları merkezi" (% 11.01) ve "Gürcistan'da belediye evi projesi" (% 10.37) olarak tespit edildi. En az tercih edilen sipariş ise "Eskişehir'de kompresör istasyonu" (% 7.81) olmuştur. Bu müşteri siparişleri arasındaki seçim önerisi, kriterlerin önceliklerinin amaç fonksiyonunun katsayıları olduğu ve firmanın dizayn ve üretim kapasitesi kısıtının göz önüne alındığı bir sırt çantası problemi çözülerek yapılmıştır. Bu çözüm yapısal çelik imalat firmasının karar vericilerine sunulmuş ve çözüme istinaden birinci, ikinci ve dördüncü müşteri siparişlerinin seçilmesi önerilmiştir. Karar vericiler bu öneriye uygun olarak bu siparişleri seçmişlerdir.

Tesis yerleşimi tasarımı, aynı zamanda, üretim sürecinin verimliliğini en üst düzeye çıkarma ve üretim maliyetini en aza indirme açısından bir üreticinin genel operasyonlarının önemli bir bileşenidir.

Tesis tasarımında “ürün çeşitliliği ve miktarı”, “ fabrika şekli ve ölçüleri”, “malzeme taşıma tipi”, “fabrikadaki kat sayısı”, “geri dönme ve atlama”, “alma ve bırakma yerleri” şeklindeki fabrika karakteristikleri göz önüne alınmalıdır.

Ürün çeşitliliğine dayanarak, tesis tasarımı statik veya dinamik olabilir. Çalışmaya konu yapısal çelik firması için fabrika dizaynı statiktir ve üstlenen projeler her sipariş için kendine özgü olduğu ve çok geniş bir ürün diyagramı bulundurduğu için tesis tasarımının her sipariş için yeniden tasarlanması gerekir. Tesis tasarımı problemi, departmanların üst üste çakışmamasını ve malzeme taşıma maliyetlerinin toplamının minimize edilmesini göz önüne alarak, değişen ürün siparişlerine dayalı olarak tesis alanında ilgili departmanların konumlarının bulunmasına odaklanmaktadır.

Bu çalışmada, yüzey temizleme, üretim öncesi astarlama, kesme, delme & zımbalama, birleştirme & raybalama, kaynak, bitirme, kalite kontrol ve yüzey işlemleri olmak üzere dokuz farklı proses ve bu proseslere ilişkin yirmi üç farklı departman yer almaktadır. Söz konusu departmanlar eşit olmayan dikdörtgen alanlara ve serbest yerleştirilmeye ihtiyaç duymakta ve yerleşim sürekli bir zemin alanında oluşturulmaktadır. Departmanların en ve boy uzunluk parametrelerinin belirtilmesinde ilgili makinelerin eni, boyu, alma ve bırakma noktaları, malzeme taşınması için gerekli mesafeler, işçinin çalışması için gerekli mesafeler göz önüne alınarak tespit edilmiştir.

Departmanlar arasındaki iş akışının tespiti ise fabrika müdürünün deneyimleri doğrultusunda tayin edilmiştir.

Tesis tasarımı aşamasında, yapısal çelik üretim sürecinin karmaşıklığı dikkate alınmakta ve tesis yerleşiminin karmaşık tam sayı programlama matematiksel modeli AMPL yazılımı ile tanımlanmakta ve Couenne çözüm aracı kullanılarak departmanların lokasyonlara atanması olurlu çözüm bulunmaktadır. Mevcut fabrika düzeni üretimde göz önüne alınsaydı, toplam üretim maliyeti 1,350,435 USD olacaktı. Öte yandan, önerilen matematiksel modelin toplam üretim maliyeti ise 1,072,442 USD olarak hesaplanmıştır ve bu maliyet mevcut konum maliyetinden %20 daha azdır. Sonuç olarak, problemin bulunan çözümü, incelenen şirket tarafından uygulanmıştır.

Çalışmaya genel olarak bakıldığında firmaya uygun kriterler tespit edilerek firmanın kapasitesini aşan olası siparişlerin öncelik sıralamasının yapıldığı ve bu sıralama sonucunda elde edilen öneriler doğrultusunda çalışmaya konu üretici ile siparişlerin seçildiği ve bu siparişlerin bir girdi olarak fabrika yerleşim programına aktarılarak bu siparişlere uygun fabrika taşıma maliyetlerini minimize eden bir fabrika yerleşim yapısının çözülerek firmanın karşı karşıya kaldığı problemlerin ardışık bir şekilde ele almasıyla çözüm sunulduğu görülmektedir. Sonuç olarak, bu çalışma, akademik çalışmalar ve endüstriyel sorunların birlikte ele alınmasına yönelik bir anlayış sunmayı amaçlamaktadır. Literatür araştırmalarına dayanarak, çelik endüstrisindeki imalat şirketleri için çok kriterli karar verme ortamında müşteri siparişlerini önceliklendiren ve tesis düzenini eşzamanlı olarak tasarlayan ilk çalışmadır. En uygun sipariş alternatifleri arasında seçim yapma ve tesislerini, seçilen sipariş(ler)e uygun olarak, taşıma maliyetlerini en aza indirgemek amacıyla tasarlama konusunda doğru kararı almak isteyen şirketler, en önemli kriterler ve kısıtlara dayanan teknikler kullanmalıdır; ancak bu teknikler yönetimsel karar vericiler tarafından kolayca anlaşılamaması durumunda kullanılamaz. Sipariş seçimi değerlendirmesi ve fabrika yerleşimi tasarımı için teknik eksiklik olmamasına rağmen, bu teknikleri mantıklı bir şekilde uygulanabilir bir süreçte düzenlemek için bir çerçeve eksikliği vardır. Bu tezin özü, daha önce literatürde ele alınmayan şekilde yapısal çelik üretimi firmaları için gerçek verileri kullanarak kapasitelerini aşan sipariş alternatiflerinden uygun olan(lar)ı seçmek ve bu sipariş seçimini, fabrika yerleşimi tasarımıyla bütünleştirmektir.

1. INTRODUCTION

Steel plays a crucial role in the development of modern societies. The steel industry is an integral part of the circular economy model that promotes zero waste, a reduction in the amount of materials used, and encourages the reuse and recycling of materials (Url-1).

Global apparent steel use increases as stated in Short Range Outlook (SRO) released by the World Steel Association; one of the largest industry associations in the world representing approximately 170 steel producers producing 85% of world steel production (including 9 of the world's 10 largest steel companies), national and regional steel industry associations, and steel research institutes (Url-1). According to the forecasts of SRO, the global apparent steel use will increase by 1.3% to 1,535.2 Mt in 2017 following the growth of 1.0% in 2016. In 2018, it is forecasted that world steel demand will grow by another 0.9% and will reach 1,548.5 Mt.

As 50% of world steel production in is used by construction industry, it is inevitably one of the most important steel-using industries (Url-1). Buildings, from houses to factories to schools to shopping malls, rely on steel for their strength. Strength is not the only competitive advantage of structural steel over other materials in the construction industry; as well as its strength, as a result of its other advantages such as aesthetics, precision and malleability; architects are able to explore creative ideas and fresh solutions. Using structural steel offers architects more design freedom in color, texture and shape. It is fast and efficient as being manufactured at factory site and requiring minimum on-site labor. It is easier to make changes in building functions such as wall repositioning, increasing floor loads, etc. Structural steel framing provides long span distances so more open space. When a building with steel structure is demolished, its components can be reused or recycled. Structural steel buildings are stronger in terms of earthquake behavior. Structural steel is significantly lighter than its equivalents and requires less extensive foundations.

Contrary to these competitive advantages, unlike many countries in the Turkish construction industry steel structure system is more expensive than the other systems (e.g. reinforced concrete). Besides being cheaper, the reinforced concrete works are handled in the construction site which allows the manufacturing companies to expand or downsize their company by hiring more labors, equipment, etc. or less so not to have initial investment costs or continuous indirect costs. Steel structures require a factory site that incurs these direct and indirect costs to the manufacturing companies. According to the views of industry experts, due to the nature of the steel structure industry, the vast majority of the work, nearly 90%, is completed in the design and manufacturing phases; the installation, remaining 10%, is done with a very little workmanship. Therefore, while the design and manufacturing capacities are stated as capacity constraints for these companies, the need of installation man-power is not stated as one.

1.1 Purpose of Thesis

The capacities of structural steel manufacturing companies are limited in terms of the amount of material they can produce in terms of design and manufacturing capacities. There is a limited design capacity because these companies have in-house technical design departments which consist of a certain amount of engineers and technicians. Moreover, there is a limited manufacturing capacity because these companies have production facilities in which there are machines with certain manufacturing capacities. Therefore, these manufacturing companies may have to choose between requests that exceed their capacities. In this case, choosing the right order(s) from among these requests is a problem that must be solved. When this first problem is solved, second problem of how to produce these chosen order(s) with the cheapest cost arises. If not all of these problems are addressed properly, it leads to time, money and opportunity losses for the structural steel manufacturing companies.

The purpose of the thesis is to solve these problems by considering multi-purpose decision making and optimization sequentially. Multi-purpose decision-making is used in order to solve the first problem and a decision framework proposal for customer order prioritization with a case study for a structural steel manufacturing company is developed. The problems are solved sequentially by defining the solution of the first problem as the input of the second problem and optimization is used to solve the second problem by building up a decision support model for facility layout design of make to order offsite products. The general form of proposed methodology is stated in Figure 1.1.

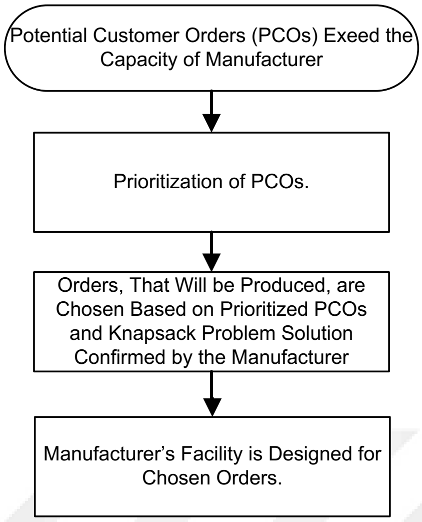

Figure 1.1 : The general flow of proposed methodology.

The industrial approaches of design problems generally suffer from the lack of data to be used. On the other hand, existing academic algorithms require little input data and cannot be applied to industrial problems. Thus, there is a great demand to combine both approaches. An intensive collaboration with industry is required to collect the data needed to model the full real-world product line design problem (Rekiek and Delchambre, 2006).

Although the adaptation of algorithms to the real-world facility design problems will be useful for the companies in order to achieve the optimal solutions, only a few companies prefer to use published techniques to improve their facility design because they do not want to share their substantial information (Lucertini et al. , 1998, Rekiek and Delchambre, 2001, Rekiek et al., 1999). Moreover, because existing academic algorithms use small amounts of input data, it is not possible to apply them to the industrial problems. As a result of the lack of information this studies just solve the fictitious problems rather than real (industrial) ones. Thus, rather than making effort for benchmarking fight, overlapping the two perspectives and dealing with more real constraints are clear needs for facility design (Petit, F., 1999).

This study aims to combine the practical information and academic methods and be an insight for the similar studies. The proposed framework of this study for the order prioritization and facility layout process are given in Figure 1.2.

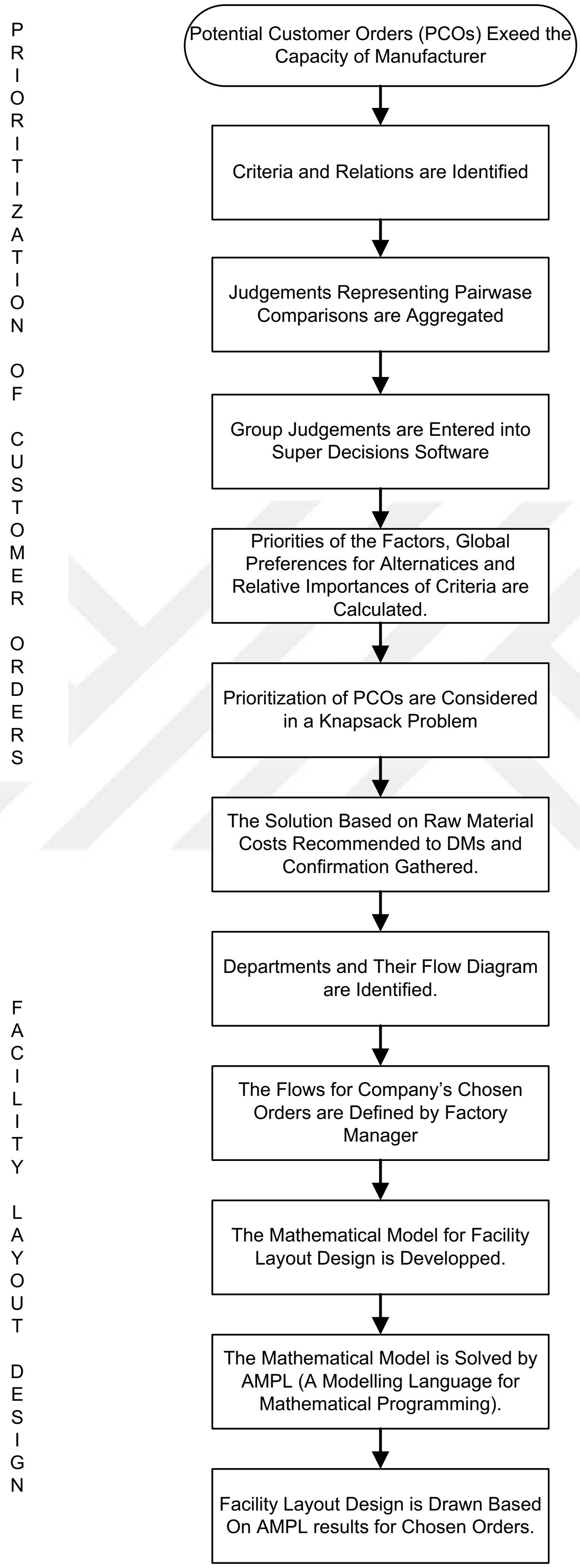

Figure 1.2 : The proposed framework for the order prioritization and facility layout process.

1.2 Prioritization of Customer Orders

Because of cost and capacity challenges, the structural steel manufacturing companies, to gain competitive advantage, should tackle some problems. The first one is being able to have enough orders to use all of their capacities in order not to deal with extra direct and indirect costs per product unit. When the company is successful with this problem, it confronts another important one: which customer order should be taken into consideration.

Demand management should be considered as a very crucial issue to maximize the profit of these steel manufacturing companies of which capacities (production capacity and design man-power capacity) are inadequate for the incoming demand (Guerrero and Kern, 1988; Whybark and Wijngaard, 1994; Harris and Pinder, 1995; Sridharan, 1998). Having efficient methods for deciding whether to accept or to reject an order while meeting company's requirements and expectations in a competitive environment is very important in this situation. As a result, several evaluation criteria based on these requirements and expectations should be considered when the company has to make an order prioritization decision.

In the prioritization part of the study, based on literature review and judgements of the managers, the evaluation criteria set is determined as “the potential profit rate per unit of time”, “the compatibility of potential order with the available capacity”, “the level of potential future order with higher profit”, “customer credit of future business opportunity”, and “the negotiability level of production schedule for the order”.

When the order acceptance decisions are made by a number of team members, different opinions are usually inevitable, so the decision process is very difficult. In such a case, developing a group decision-making model that takes into account everyone's opinion and establishes the best possible decision is very important. They select among a set of customer orders, which can be regarded as alternatives that should be evaluated on the basis of several, usually conflicting, and incommensurable criteria which may have different priorities. Therefore, the treatment of the decision problem of prioritizing consumer orders necessitates a multi criteria decision-making (MCDM) approach.

As will be explained later, there are interconnections among constituents of the decision model: The criteria as well as alternatives affect (depend on) each other. For this reason, in this study, an Analytic Network Process (ANP)-based group decision framework that will allow the company to choose the most appropriate projects among the alternatives under its limited capacities while considering the evaluation criteria are developed.

Although the Analytic Hierarchy Process (AHP) is one of the widely used methods to prioritize criteria and alternatives, AHP fails whilst there are dependence and feedback among criteria and alternatives. Because of these interconnections of the network model, the constituents that are less important individually might turn out to be more important when evaluated collectively. That is why ANP introduced by Saaty (1996), is selected as the research methodology.

Some examples of ANP applications in the literature include manufacturing decisions (Bayazit and Karpak, 2007; Karpak and Topcu, 2010), energy management (Liang et al., 2013; Xu and Chan, 2013; Aragones-Beltran et al., 2014), supplier selection (Hsu and Hu, 2009; Ming-Lang et al., 2009; Abdollahi et al., 2015; Lin et al., 2015; Hashemi et al., 2015), competitiveness and the performance of the businesses (Joshi et al., 2013; Lin et al., 2011). The construction industry related studies in which the ANP approach is utilized are generally concentrate on the supplier selection (Eshtehardian et al., 2013) and the causes of disruptions in the process (Cakmak and Cakmak, 2013).

There is a lack of literature for prioritizing customer orders considering several criteria. Based on the literature survey, the prioritization part of this study is the first demand management research methodology proposed in the structural steel industry. The prioritization part of this study aims to concentrate on structural steel manufacturing companies that want to prioritize a set of potential customer orders satisfying multiple criteria when they confront the mentioned capacity problems under the situation of having potential orders that exceed the current capacity. Besides the importance of evaluation criteria used for prioritization of orders are also revealed.

The approach in the prioritization phase of this study is to conduct a case study of a Turkish structural steel manufacturing company. After the identification of related criteria for the evaluation of possible alternatives, ANP is used to prioritize the criteria and the alternatives based on the aggregated pairwise judgments of the managers.

The prioritization part of this study consists of main sections as follows. At the beginning section, the literature review that consists of customer order prioritization in steel industry and evaluation criteria for order prioritization are pointed out. In the second section, the research methodology utilized is expressed by explaining the decision making process and describing the ANP method. Third section exhibits a real life case study. The case company, the decision makers as well as the constituents of the decision model are introduced. Data, data sources, data collection and findings are clarified.

1.3 Facility Layout Design

The structural steel manufacturing process is so complex because of the uniqueness of steel projects and the very wide product mix. These force the manufacturing companies to design specifically the facility layout in accordance with the manufacturing process of the current project on hand. Besides the complexities involved in structural steel manufacturing, currently still facility planning, scheduling and estimating activities are realized by the manufacturing engineers and factory manager's experiences in most of the manufacturing companies. However, it is clear that analytical models will be much more useful to achieve process improvement and productivity.

After preparing design, detailing and shop drawings, generally structural steel manufacturing is a process where a steel piece (plate or section) is cleaned and then processed in accordance with the shop drawings, in which all component details about the dimensions, quality, location to be fitted together with other components etc. are stated.

The structural steel manufacturing process, that start with surface cleaning operation, continues with prefabrication priming to prevent the raw material from rust. Later, the raw materials are cut into the right dimension stated on the shop drawings with circular saw, gas or flame cutting or plasma cutting operations. As again stated in the shop drawings these cut materials are drilled or punched to manufacture sub products. After the manufacturing of sub products, they are fit together manually with pointed welding-fits as shown in shop-drawings. Later, the product is semi-automatically welded while acquiring the required strength. Afterwards, non-destructive testing is realized to make the quality control of the steel elements. Finally, the controlled fitted sub-product group is finished to a smooth surface and coated for surface protection by epoxy paint, galvanizing, etc. by the surface treatment operations.

The factory characteristics namely “product variety and volume”, “facility shapes and dimensions”, “material handling system”, “number of floors in the facility”, “backtracking and by passing”, and “pick-up and drop-off locations” should be considered in the design of the facility layout.

In the most studies, the facility design is supposed to be static as it is assumed that the facility design will remain constant for a long period of time. The facility design should be also static for the structural steel manufacturers and it should be redesigned with new orders as a result of being awarded for projects that takes sometimes years to produce, covers a large part or sometimes all of their capacities and differs in each time.

The most commonly used formulations for facility layout design is Quadratic Assignment Problems (QAP) and Mıxed Integer Programming (MIP). MIP which is used for continuous layout design is preferred in the static layout design of the structural steel manufacturing company. MIP’s advantages can be listed as the following: rectangular shapes of all workstations, no need of an initial layout, guarantee in non-overlapping of workstations, high reliability by computer simulation. Exact methods (branch & bound, cutting plane, dynamic programming, decomposition approaches) and heuristic methods (construction and improvement heuristics, metaheuristics, hybrid approaches) are used in resolution of facility layout formulations.

In this study, a mixed integer model is developed for the problem in hand and this model is identified in the software AMPL (A Modeling Language for Mathematical Programming) Integration of Prioritization and Facility Layout) that provides rapid development and reliable results. After the formulation of the problem in AMPL, the solver Couenne (Convex Over and Under ENvelopes for Nonlinear Estimation) is used to solve the problem. Couenne which aims at finding global optima is an open source branch & bound algorithm for solving mixed integer nonlinear programming (MINLP) problems and finds globally optimal solutions to nonlinear problems regardless of convexity. It implements linearization, bound reduction, and branching methods within a Branch & Bound framework.

The facility layout design part of this study consists of main sections as follows. At the beginning section, the literature review that consists of factory characteristics and static & dynamic layout systems is pointed out. In the second section, formulation of layout problems is expressed by explaining formulations of QAP and MIP. In the third section, the resolution approaches namely exact methods and heuristic approaches are declared. While fourth section covers information about AMPL, in the fifth section model solvers are introduced. Finally, sixth section exhibits a real life case study. Problem definition, factory characteristics, fabrication processes in structural steel manufacturing company, assumptions, equipment list and required area for operations, flow frequencies, cost of moving a part, mathematical model of the case study, cost of problem with current layout and cost of problem with mathematical model are specified in real life case study part.

2. PRIORITIZATION OF CUSTOMER ORDERS

2.1 Literature Review

2.1.1 Customer order prioritization

At the point when companies receive a demand of a customer, the experts of the companies assess if the demand is suitable for their capabilities or not. If it is not suitable, they inform the customer that they will not be able to quote for the demand and they end the process. If it is suitable, then a further step namely prequalification may occur. If the customer requests the prequalification, the prequalification documents are prepared by the related departments and presented to the customer. As long as, the customer decides that the company meets the requirements of the qualification, or prequalification is not requested; the related department prepares the quotation. After the assessment of the customer of the received quotations, there is generally a short-list of potential suppliers with whom the customer decides to negotiate. In this progression, if the quotation of the company is stated in this short list, it is one of the other several potential demands according to the perspective of the supplier company. If these potential demands exceed the supplier's capacities, at that point this supplier has to make choices among them. In many make-to-order companies which is highly loaded, the manufacturer reject processing some orders by either outsourcing them or rejecting them altogether (Shabtay et al., 2013).

Usually there is not a formal consideration of companies to accept or reject the orders. Instead, the sales department focuses on accepting as many orders as possible to increase the company profit and of course its own premium, while the design and procurement departments try not to accept the order(s) by considering the promised delivery deadlines to be in safe even sometimes it is an unnecessary protection. To avoid the conflict of interest between these departments, which can cause delays, violated delivery dates and excessive use of highly expensive non-regular capacity usage, an integration of order selection is required (Guerrero and Kern, 1998; Herbots et al., 2007; Zijm, 2000). Sridharan (1998) presents capacity rationing, order promising subcontracting, and mechanisms for improved coordination between the different departments of the company where the total potential orders are greater than the available capacity.

The choices between the potential orders might be biased to certain alternatives for some reasons for instance intuitive decisions of managers, as a result of the limited evaluation capacity of human being under numerous criteria. Utilizing a systematic, analytic, quantitative, and scientific approach for order prioritization would be more accurate, defendable, and justifiable.

In order to maximize the profit, this crucial managerial issue of accepting/rejecting the demand under limited capacity, has taken attention by many researchers. In order to make this decision, the searches are used several different structures for the problem and also methods. For instance, Hung and Lee (2010) are focused on the order selection decision problem for apparel contract manufacturers. They assume that the arrival of future customer orders is a Poisson process, the capacity requirement of a future customer order is a continuous random variable and the profit per unit capacity used by an order is also a continuous random variable. Under these assumptions they use the following procedures SPCR (Static Probability Capacity Rationing Decision Procedure) and DSCR (Dynamic Stochastic Capacity Rationing Decision Procedure) in order to accept or reject an order. Wang et al. (1994) have also focused on make-to-order companies and in addition they have clearly pointed out that the non-negotiable order acceptance is considered in their study. They present a neural network approach for order acceptation/rejection decision, besides they model the problem as a sequential multiple criteria decision problem and purpose a feed-forward neural network model. This network formulates the business development manager's preference and is based on preference model to evaluate and prioritize orders, finally develops a decision rule to select order from prioritized order list. In addition, Bone and Mowen (2010) has also focused on customer selection but in service companies. Their model is based on service employee's desire for decision latitude (DDL) in order to decide whether to provide a service to a potential customer or not.

On the other hand, there are several more researchers who have focused on the dynamic world of construction sector and deal with selection problem. For instance, Hatush and Skitmore (1998) has used a multi-criteria utility theory for contractor selection. They use both quantitative and qualitative criteria where stake-holders alternatives occur. Although the main objective of contract bidding strategy is commonly supposed to be the profit maximization, they are also considered with other issues such as corporate goodwill, market share, and future growth. The five criteria: comprise financial soundness, technical ability, management capabilities, safety performance, and reputation are used with bid amount in multi-criteria model and each of these five criteria is divided into four sub-criteria. They used a point score system (0-20) for each criterion and they suggest selecting the best contractor according to the additive model results.

Which projects the companies should spend their limited resources on decisions are assisted by some researches with models of Portfolio Decision Analysis (PDA) which: (i) capture relevant information about project candidates, evaluation criteria, selection constraints and uncertainties, and (ii) synthesize such information into decision recommendations with appropriate techniques of decision analysis and optimization (Mild et al., 2015). For instance, Archer and Ghasemzadeh (1999), Cooper et al. (1999) and Henriksen and Traynor (1999) focused on projects available for selection than can be undertaken within the physical and financial constraints of a company, so choices must be made by project portfolio analysis.

There are also researches that have made their research based on literature review of the topic. For instance, Chai et al. (2013) have presented a systematic review of supplier selection articles from 2008 to 2012 on the application of decision making techniques. They pointed out that there are many new approaches and techniques that are focused on the concept of supplier selection. They have also given a summarization list of literature review under the following headings: “approaches”, “core decision making techniques” and “additional features of decision approaches”. They have declared that analytic network process (ANP) is used in 12.20% of these reviewed articles. Based on their list and declaration, it can be syllogized that one of the most preferred methods of the articles in the literature is ANP. Moreover, Ho et al. (2010) have made a similar literature review from 2000 to 2008. They have also denounced ANP as one of the widely used multi-criteria decision making technique as well as Analytic Hierarchy Process (AHP), Case-Based Reasoning (CBR), Data Envelopment Analysis (DEA), Fuzzy Set Theory, Genetic Algorithm (GA), Mathematical Programming, Simple Multi-Attribute Rating Technique (SMART) and their hybrids.

Furthermore, some researchers study order acceptance and scheduling problems together in their searches. For instance, Slotnick and Morton (1996), Ghosh (1997), Slotnick and Morton (2007), and Rom and Slotnick (2009) focus on order acceptance and scheduling problems for a single machine environment without preemption. In all these studies, the aim is to maximize the total profit, that is difference between the sum of revenues and total weighted tardiness. Slotnick and Morton (1996), establish a branch and bound algorithm together with a beam-search heuristic and a myopic heuristic, while Ghosh (1997) states that the problem is NP-hard in the ordinary sense and gives two pseudo-polynomial time algorithms and a fully polynomial time approximation scheme. Slotnick and Morton (2007) use tardiness in the objective function and use similar algorithms with their 1996 study. On the other hand, Rom and Slotnick (2009) use a genetic algorithm and make a comparison with the myopic heuristic of Slotnick and Morton (2007). Kalantari et al. (2011) present a novel decision support system for order acceptance/rejection in a hybrid MTS and MTO manufacturing environment. They use a fuzzy TOPSIS method to prioritize the orders and than they calculated tough-cut capacity and rough-cut inventory. In case of unavaliability in capacity and materials, they reject some orders. For the accepted orders they calculated prices and delivery dates by running a MIP model. Charnsirisaksul et al. (2004) focus the order selection and scheduling decision in a preemptive single machine environment to maximize the producer's profit expressed as revenue minus production, holding and tardiness costs and suggest a time-indexed MIP formulation for solution. Balakrishnan et al. (1996) present a rationing model for a single period for MTO companies where the demand is stocastic. They consider a rationing policy to allocate capacity to two different classes of products namely high priority and low priority orders. Wester et al. (1992) evaluate order acceptance and scheduling in a single machine production system where there are setup times based on order types. Their study is different than above studies in such a way that they reject tardy order(s) and use simulation to evaluate different strategies under random order arrivals. Furthermore, Roundy et al. (2005) solve an order acceptance problem for a facility environment. In his study, the accepted incoming orders are inserted into the current schedule by forming manufacturing batches, and minimizing setup and holding costs are aimed, based on the batch-sizing decision. He develop an IP formulation and several heuristics for solution of the facility problem. Chen et al. (2008) focus on making a selection among incoming orders and optimizing the sequence of these selected orders under multiple constraints while cpnsidering minimizing the sequence dependent transition costs and non-execution penalties ad objective function. He develop a hybrid genetic algorithm that benefits from extremal optimization.

2.1.2 Multi-criteria decision making techniques

Multi-criteria Decision Making Techniques (MCDM) is a methodological framework that cover a finite set of alternatives (also known as actions, objects, solutions, or candidates), while being evaluated from multiple viewpoints, called criteria (also known as attributes, features, or objectives). The main goal of MCDM is providing knowledgeable information and recommendation to decision maker. “Multi-attribute utility methods” is one of the categories which based on the principle behind MCDM techniques. Both Analytic Hierarch Process (AHP) and Analytic Network Process (ANP) are well-known multi-attribute utility methodologies. These methods consider about assigning a utility value to each given alternative. The preference degree that can be the basis for ranking or choice is represented by the utility value (Chai et al., 2013).

2.1.3 Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP)

The Analytic Hierarchy Process (AHP) is a relative measurement theory with regard to paired comparisons used to derive normalized absolute scales of numbers whose elements are then used as priorities (Saaty, 2007). AHP acts as a feedback mechanism to review and revise judgments for the decision makers so the consistency verification operation of AHP contributes greatly to prevent inconsistency (Ho et al., 2009).

Saaty (2000) has also developed ANP as an extension of AHP. ANP is a general theory of relative intangible attribute measurement. ANP handles the measurement of qualitative or intangible attributes by using pairwise comparisons along with expert judgments, like AHP (Chai et al., 2013). Yuksel and Dagdeviren (2007) have applied ANP for their SWOT analysis, because AHP is not appropriate to take into account dependence among factors.

ANP is stated as the most preferred method because of its effectiveness in ranking and task choices. ANP is also a widely used component because it provides constitute up-to-date decision approaches (Chai et al., 2013). Besides, the other most important advantages of ANP are its abilities in incorporating dependencies and feedback, analyzing and representing interactions, and synthesizing their mutual effects by a single logical procedure (Sarkis et al., 2002).

There are many articles, researches about ANP approach and also lots of created models and approaches which constructed with ANP. Recently, contributors apply the ANP in many managerial areas. For instance, ANP is used to determine the weights of criteria in a simple hybrid approach which introduced by Lin et al. (2010). In addition, Tseng et al. (2009), constructed an sequential model and in this model ANP is used for criteria analysis. Furthermore, Demirtas and Üstün (2008, 2009) have published three articles about integrated decision models that involve the ANP technique. Moreover, Onut et al. (2009) published a case study concerning telecommunication companies, in which ANP was utilized. Additionally, Sarkis and Talluri (2002) stated that in the evaluation process, the internal interdependency needed to be considered and they used ANP approach to evaluate and select the best supplier with respect to strategic performance metrics and organizational factors. Also, Bayazit (2006) constructed an ANP model which includes ten evaluating criteria about supplier’s performance and capability cluster. He considered each of criteria as a controlling factor for pairwise comparison matrix to formulate interrelationships among all criteria. On the side, Gencer and Gurpinar (2007) implemented an ANP model in an electronic company.

Thomas Saaty is generalized AHP to enable potential interactions, interdependences and feedback and called this multicriteria decision making toll as ANP (Sevkli et al., 2012; Lee et al., 2009). ANP allows to obtain relative priorities from individual judgements based on the pairwise comparisons (Asan and Soyer, 2009).

2.1.4 Evaluation criteria for order prioritization

In this study a multi criteria decision-making process is used for order prioritization, because there will be several, conflicting, and incommensurable criteria. The evaluation criteria revealed from the literature and their brief explanations are given in Table 2.1.

Table 2.1 : Evaluation criteria.

Criterion	Resource	Explanation
The potential profit rate per unit of time	Wang et al., 1994	The potential profit ratio that considers the profit for a given time period
The compatibility of potential order with the available capacity	Balakrishnan et al. 1996; Patterson et al., 1997; Barut and Sridharan, 2005	The suitability level of the potential order in terms of companies' limited capacity
The level of potential future order with higher profit	Hung and Lee, 2010	The level of possibility of receiving a future demand that is much more profitable than the one in consideration
Customer credit of future business opportunity	Wang et al., 1994	The level of being a loyal customer of the manufacturing company
The negotiability level of production schedule for the order	Wang et al., 1994	The level of flexibility of the project in terms of project schedule

Maximizing the profit is a mandatory goal for profit-making nature of business. Order acceptance decision has a great potential to improve the overall profitability of the company (Aouam and Brahimi, 2013). A demand with higher profit margin but a longer operation time may not be profitable when it is compared with a demand with lower profit margin but a shorter operation time (Wang et al., 1994). Therefore, instead of total profit, "the potential profit rate per unit of time" can be specified as an evaluation criterion for the order prioritization decision.

In production industry, companies ordinarily employ two common manufacturing strategies, make-to-stock (MTS) and make-to-order (MTO). Finished products are stocked by MTS producers to have the control of variety of demands (Arredondo and Martinez, 2010), on the other hand MTO producers are process-focused and produce unique products which vary in design, usage, or any other different specifications (Mestry et al., 2011). Since the products' inventories are scarce resources for make-to-stock producers, the concept and methods for allocating inventories are essential. Some of these concept and methods are mentioned by Nahmias and Demmy (1981), Haynsworth and Price (1989), Rinks (1989), Ha (1997). On the other hand, make-to-order producers are not able to manufacture before the confirmed demand. The constraints of these producers are workload and production capacities. Allocation problems have been examined for these make-to-order companies (Balakrishnan et al. 1996; Patterson et al., 1997; Barut and Sridharan, 2005). Enns (2000) and Enns and Costa (2002) consider the input control at the facility by focusing on aggregate workload measures. Nandi and Rogers (2003, 2004) develop a MTO production system under a control policy considering an order acceptance/rejection component by using simulation. Moreira (2005) evaluate the facility as a multiple decision-making problem and focused on the acceptance/rejection decision. As a result of the construction industry nature, the company under the consideration of this study is not able to stock the product but produce it in job shop under the restrictive manufacturing capacity. In addition to manufacturing capacity, the workload capacity is also limited for design and installation processes. Hence, "the compatibility of potential order with the available capacity" is defined as a criterion for the prioritization decision.

If there is a potential for a continuous long-term high demand, the company can prefer to expand the capacity by investing or purchasing a new facility. However, if it is a short-term problem, increasing the capacity is not possible as a result of the time constraint. Hence, a mandatory decision occurs for the short-term problems to make a choice between the orders by allocating capacities. For MTO companies, accepting the order also may cause another problem by affecting the accessible capacities for the future demands (Hung and Lee, 2010). Because accepting an order when there is a scarce capacity will cause infeasibility for accepting more profitable orders which can occur in the near future. It is an interesting facet of order selection policies to take opportunity loses into account (Defregger & Kuhn, 2007; Mainegra Hing, van Harten, & Schuur, 2007; Wouters, 1997). To consider opportunity loses Nawjin (1985) developed a single server system in continuous time. In his system a decision of starting a new service for an arriving order or rejecting it depending on its expected processing time should be made. Opportunity loses can be considered by a dynamic programming model in a natural way (Herbots, Herroelen, & Leus, 2007). The decision can be done based on the solution of an incoming order is made eligible for acceptance only if its immediate reward per unit of capacity is greater than the average reward. In this study the short-term problems of the company are concentrated on and "the level of potential future order with higher profit" is regarded as another criterion which should be considered by the managers based on their experiences.

Customer credit of future business opportunity should also be taken into account in prioritization of the demands. Customer credit is based on the customer's financial condition and previous history of purchases (Unclues et al., 2003), backlog and customer's commitment to repurchase or patronize a preferred product consistently in the future (Oliver, 1997). If the demand of this customer type is declined, this situation may force the customer to seek alternative suppliers so the manufacturing company can lose the future business opportunities (Wang et al., 1994). Therefore, although the order of a customer is not profitable in the comparison with its alternatives, manufacturer may sometimes prefer to accept its order. Hence, "customer credit of future business opportunity" is stated as an additional criterion of the model.

The decisions of order acceptance and its production timetable are generally not made independently by neither the client nor related managers. Conversely, these decisions are accumulated through negotiations between the counterparts (Wang et al., 1994). Hence, "the negotiability level of production schedule for the order" can be considered as another criterion.

2.2 Research Methodology

2.2.1 The decision making process

At the point when a customer's demand is suitable for the capability of the manufacturer and the customer believes that the manufacturer is qualified, this demand becomes one of the several potential orders. In the condition where the potential orders exceed the capacities of the manufacturer, a selection among them should be done by the manufacturer. In this study, rather than use of intuitive and potential biased decisions that will be made by managers (decision makers; DMs), utilization of an MCDM based framework is proposed to help managers to prioritize the potential orders exceeding the capacities. The proposed decision making process includes three main stages:

1. Structuring the problem on hand
2. Constructing the decision model

3. Analyzing the model

Each stage contains several steps that are explained in detail at Figure 2.1 and in the following subsections.

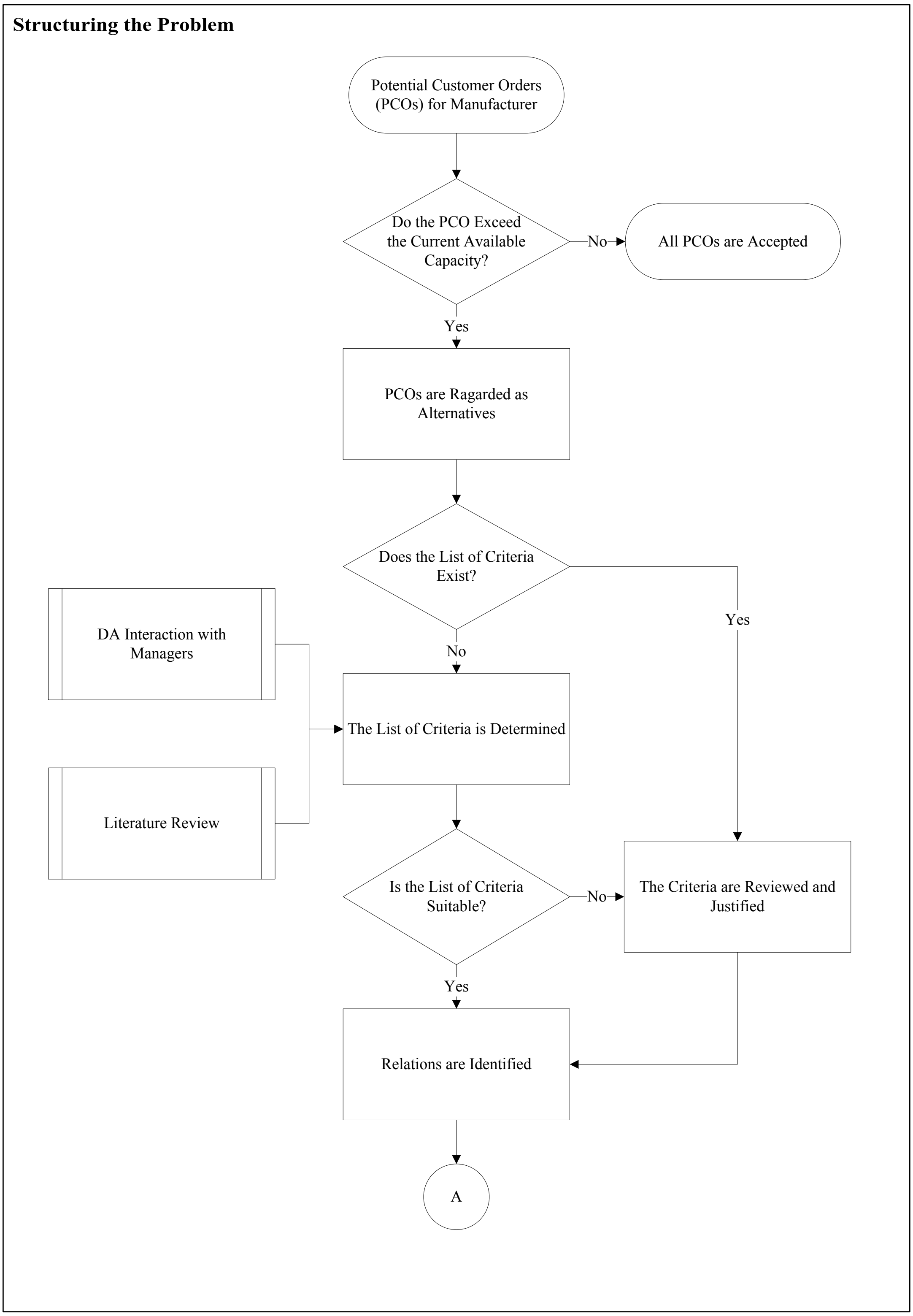

Figure 2.1 : The proposed framework for the order prioritization and selection process (Akyildiz et al., 2015).

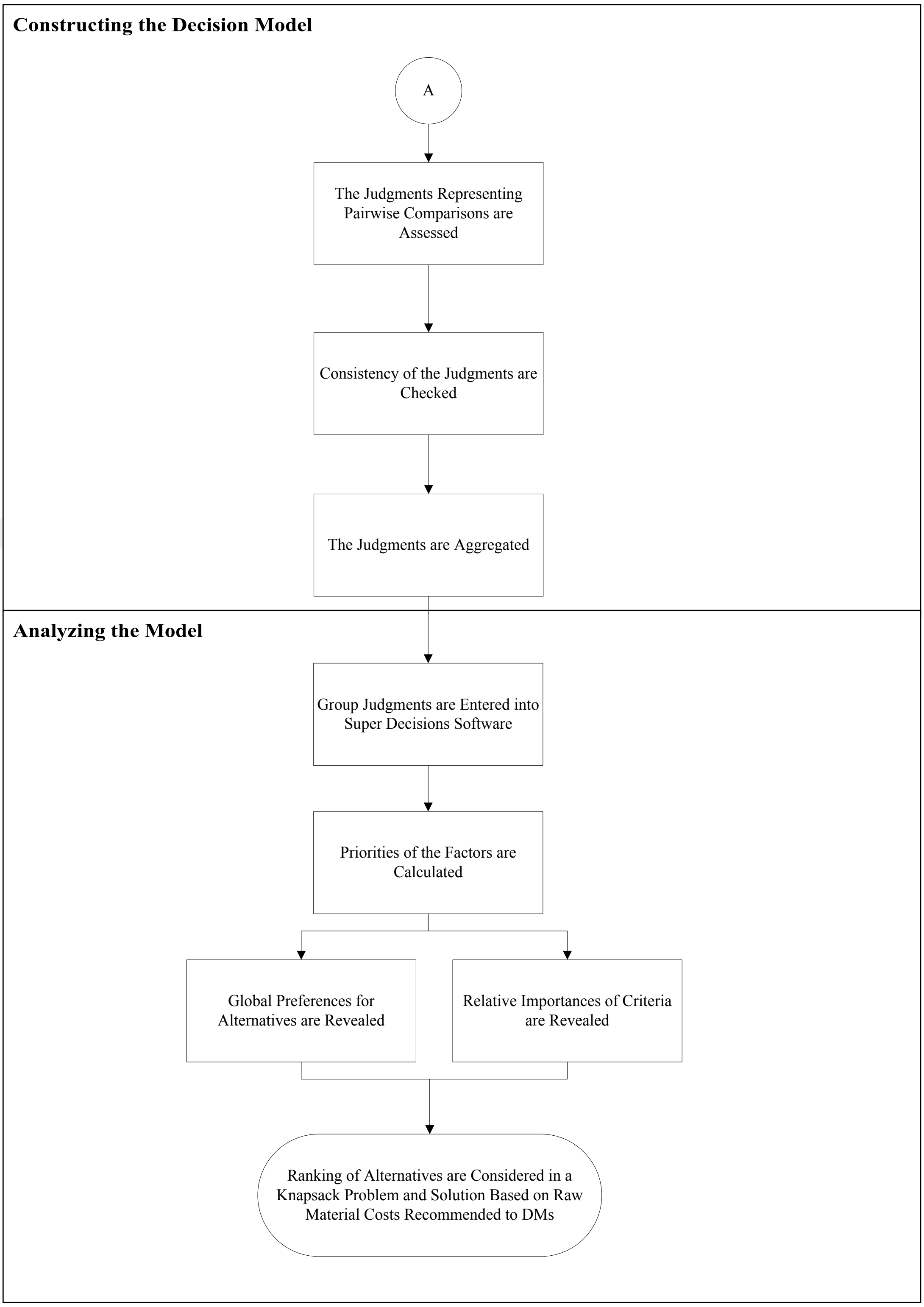

Figure 2.1 (continued) : The proposed framework for the order prioritization and selection process (Akyildiz et al., 2015).

2.2.1.1 Structuring the problem

In the current decision environment, potential orders can be identified as alternatives while the factors that are used for the evaluation of these orders can be regarded as criteria. Decision analysts (DAs) collaborate with DMs and examine literature to achieve a list of criteria. After that, this list should be examined and justified by the DMs. The DMs can make revisions on the list and the final list of criteria is used at the client order prioritization decision of that structural steel manufacturing company. As a final step of this stage, DAs ask DMs to specify the relations (effects) among criteria and alternatives.

2.2.1.2 Constructing the decision model

At the following stage, the DAs assess the judgments of the DMs. The DMs are posed pairwise comparison questions. A pairwise comparison questionnaire is sent to the managers for the purpose of assessing their judgments representing the relative influence of affecting factors (criteria and alternatives) on the affected factor for all possible pairs.

At that point, consistencies of judgments are checked. If inconsistency occurs for a DM, s/he is requested to pose the pairwise comparison questions to reduce her/his inconsistency, if s/he wishes.

At the last step of this stage, DAs compute geometric means of all paired comparison judgments for each question in order to reveal the aggregated group judgments.

2.2.1.3 Analyzing the model

At the last stage, utilizing the assess/compare module of the Super Decisions (Url-2), a decision making software based on the AHP and the ANP, these group judgments in pairwise comparison matrices are arranged by DAs. The priorities of the factors are computed utilizing the computations module of the software which does all the matrix algebra. The output of the limit matrix can be converted to the relative priorities: the global preferences for the potential projects of the manufacturer and the importance of the related evaluation criteria for the order prioritization decision problem on hand. Finally, the results are discussed with the managers.

2.2.2 Analytic network process

2.2.2.1 Why ANP?

MCDM tools are frequently used, as a result of their aims which are: Evaluating several complex knowledge, Systematic decision processes, Gathering up decision maker's subjective evaluation with expert's opinions, Analyzing the complex problems which are understandable as a whole, Facilitating communication between decision makers where there is a large number of decision makers via preparing general platform to create the environment to enable a discussion.

Because of its multi criteria nature, the problem under consideration requires an appropriate multi criteria decision method to treatment. There are many MCDM methods that can be demonstrated to model a complex decision problem including the simple multi attribute rating technique by swings (SMARTS), the simple additive weighting method (SAW), the technique for order preference by similarity to ideal solution (TOPSIS), the preference ranking organization method for enrichment evaluation (PROMETHEE), the method of "élimination et choix traduisant la réalité" (ELECTRE), and analytical hierarchy process (AHP) (Topcu, 2000). These MCDM methods assume that there is independence among criteria and among alternatives, and only alternatives affect (depend on) criteria. In more complex decisions, criteria may affect alternatives, criteria may depend on each other, and alternatives may depend on each other. Subsequently, there may be dependencies and feedbacks among the constituents of the decision model. A network model with dependence and feedback improves the priorities derived from judgments and makes prediction much more accurate.

While dealing with a network model, fuzzy cognitive maps (FCMs) that allow dynamic modelling of a system in consideration of a complex network structure can be chosen but the main purpose of the FCM is to determine the causal relationships between factors and tries to find the effects of factors on others in the long run (Kutlu and Kadaifci, 2014; Yaman and Polat, 2009). On the other hand, System Dynamics that captures the causal relationships and interdependence of the factors (Tesfamariam and Lindberg, 2005) and The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method which is used for representing the complex structure of causal relationships between factors (Jassbi et al., 2011) can also be used, but they will fail to identify the relative importance of the criteria as well as the preferences for alternatives. Contrarily, ANP, a general form of AHP, can adequately incorporate interdependent relations among components, represent and analyze interactions, and synthesize their mutual effects using a single logical procedure (Chang et al., 2009; Wang and Wu., 2008)

ANP may reveal global preferences of DMs for alternatives as well as the importance of evaluation criteria. In this study, managers can choose the most appropriate projects for their companies based on the priorities of the customer orders.

2.2.2.2 Background of ANP

ANP is a strong and understandable methodology which enables groups or individuals to combine qualitative and quantitative factors having interactions, interdependences, and feedbacks (Saaty, 1996). Relative priorities from experts' judgments based on the pairwise comparisons are obtained by ANP.

The factors related to the problem are grouped into clusters and a decision network is structured consisting of the clusters, the factors in these clusters, and the links between these factors; at the point when the problem is treated with ANP. Figure 2.2 illustrates such a network structure.

The dependency (effect), represented by the link between factors, can be arranged into two groups: inner and outer dependency. Inner dependency represents the link between the factors in the same cluster and outer dependency represents the link between the affected factor in one cluster and its affecting factors in another or same cluster. Moreover, feedback represents outer dependencies between two clusters in both directions.

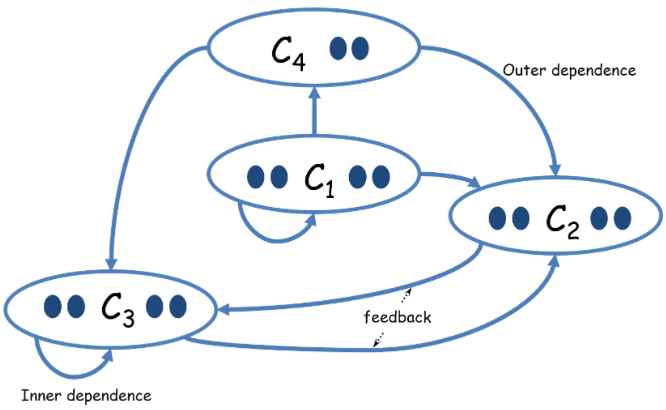

Figure 2.2 : A sample network structure (Saaty, 1996).

2.2.2.3 Basic steps of ANP

Step 1 – Structuring the Model

The initial step is structuring the network model where nodes correspond to clusters (Saaty, 1996). After determination of all criteria affecting the decision, they are grouped into clusters. The elements in each cluster may influence some elements in other clusters or it is possible for elements to have influence on others in the same cluster which can be represented as loops (Lee et al., 2009).

Step 2 - Pairwise Comparison and Local Priority Estimation

Second step consists of the formulation of links to acquire eigenvectors by following the stages respectively: cluster comparison, comparison of criteria, which are predetermined as linked, and comparison of alternatives with respect to the criteria to which they are connected. The pairwise comparisons are gathered by asking the following question: "of the affecting elements, which one influences the affected element more and how much more?". This question can be express in other words in such a way that: "How much influence does the criterion have compared to another criterion with respect to the preferences?" (Yang and Tzeng, 2011). A special nine-point scale is utilized to perform pairwise comparisons where 1 represents that two criteria has equal importance or the decision maker is indifferent between two criteria; 3 represents moderately more dominance of the first element on the second; 5, 7, and 9 represent strongly more, very strongly more, and overwhelming dominance of the first element on the second element, respectively (Saaty, 1980). The values are intermediate values for the comparisons. The reciprocal value is automatically allocated for the second element compared to the first one. For each pairwise comparison matrix, an eigenvector is computed. Eigenvector consists of priorities of the elements with respect to the element they are affecting. In conclusion, at step 2, consistency ratios of pairwise comparison matrices are computed and checked if the ratios are greater than 10% or not. If the ratio is beyond the limit, it shows that decision maker is inconsistent in her/his judgment. In such a case, questions should be asked again to reduce inconsistency.

Step 3 – Formation of the Supermatrix, Weighted Supermatrix and Limit Matrix

Each element is presented at one row and one respective column of a supermatrix (Saaty, 1996). The supermatrix represents relative importance of all elements (Sevkli et al, 2012) where local prioritiy values are entered into appropriate places (Lee et al., 2009). The computed eigenvector of the affecting elements with respect to their affected element is stated to the column representing the affected element and the rows representing the affecting. The weighted supermatirx is obtained by reducing the supermatrix to a column stochastic matrix (Asan and Soyer, 2009): if the column sum of any column in the composed supermatrix is greater than 1 (there are more than one eigenvector), that column will be normalized. By raising the weighted supermatrix to large powers, one can have a limit matrix where converged or stable values can be read. These values are the desired priorities of the elements in the network and indirects influences of each element on others can be captured (Lee et al., 2009).

Step 4 – Selecting the Alternatives

The limit matrix indicates the overall relative importance of one element on other elements in the network (Asan and Soyer, 2009). The normalized values for each cluster in limit matrix give the priorities of alternatives. The decision maker suppose to choose the alternative which has the highest priority value.

2.2.2.4 ANP implementation in construction and manufacturing industries

Up until this point, ANP methodology has proven itself to be successful when expert knowledge is utilized within business, social, and production decision problems or used to predict economic turns (Burnaz and Topcu, 2006).

In the ANP literature, there is a lack of applications related with construction industry: Cakmak and Cakmak (2013) develop a model to analyze and to prioritize the causes of disputes in the construction industry by using ANP. Eshtehardian et al. (2013) propose a decision support system to select appropriate suppliers for construction and civil engineering companies in Iran. Pakand and Toufigh (2017) introduced integrated analytic network process and genetic algorithm methodology to select the optimum mixture of Rammed earth material in a perspective of energy consumption buildings topic. Liu and Tsai (2012) developed a fuzzy risk assessment method to provide prevention and improvement technique against occupational hazards in construction industry. They used ANP to identify important hazard types and hazard causes. Lin and Jianping (2011) combined ANP and fuzzy comprehensive evaluation to evaluate risks of new campus engineering project.

Beltran et al. (2014) applied AHP and ANP to decide whether to invest in a particular solar-thermal power project, and, if so to determine the order of the priority of projects for a solar power investment company.

Despite the fact that the literature is scant in terms of the ANP applications in construction industry; there are many studies utilizing ANP in production decisions for integration with other methodologies and for supplier selection decisions. Some researchers focus on ANP utilization in production decisions. For instance, Karpak and Topcu (2010) concentrate on prioritizing the factors affecting the success and antecedents for small medium enterprises (SMEs) in Turkey. SMEs are supported by the proposed ANP-based framework to achieve their goals and take their parts in the growth of Turkish economy. Moreover, Bayazit and Karpak (2007) develop an ANP-based approach to evaluate whether the Turkish automotive manufacturing industry is ready to adopt total quality management (TQM) practices or not. Joshi et al. (2013) utilize ANP to analyze the determinants of competitiveness for automotive industry specific to the supply chain performance and two priority vectors are gathered: the first one is significant only for the automotive industry and the other one is considered to be a general framework for competitiveness. In addition, some researchers concentrate on integrating other methodologies with ANP framework in order to evaluate the factors related to a particular area. Lin et al. (2011) provide an assessment structure for strategic competitiveness of green business innovation capabilities and inspect its applicability in a manufacturing firm by using fuzzy set theory and importance-performance analysis in addition to ANP. Another hybrid approach focuses on determining the importance of SWOT factors or assessing the fit between factors and decision alternatives and it utilizes the fuzzy logic and ANP to prioritize the strategies (Babaesmailli, 2012). Other ANP model is proposed to utilize as a tool to improve the dynamic evaluation of manufacturing strategy performance evaluation and to show the applicability of supermatrix approach to the quantitative model for performance measurement systems (Sarkis, 2003).

There are also the studies that particularly based on ANP application for supplier selection. To be more competitive in the market and to deal with the problems and changes caused dynamic environment, particularly for companies, that are highly dependent on the suppliers, supplier evaluation and selection is one of the most important issues and so ANP becomes very useful for supplier evaluation and selection. Abdollahi et al. (2015) form an ANP framework for supplier selection based on product-related criteria. After prioritizing criteria with ANP, they use Data Envelopment Analysis to rank the alternatives. ANP approach is also utilized by Tseng et al. (2009) for selection of the most appropriate suppliers due to the complexity, elusiveness, and uncertainty in the nature of criteria/attribute evaluation process. They apply their proposed system on a technology company in Taiwan.

2.3 Real Life Case Study

2.3.1 The case company and the decision makers

2.3.1.1 Selection of the case company

The order prioritization decision framework was utilized for the managerial decision problem of a Turkish structural steel manufacturing company.

Although when people are faced with a problem, they first measure its similarity to a set of common or previous problems stored in their long-term memories, the company under consideration had just been facing an over-demand problem for last two years therefore it had not got a long-term memory for the issue. Therefore, company's business development manager requested to find a solution strategy to prioritize the potential customer orders and make a selection among them when there were limited design and production capacities because of currently awarded projects of the company.

2.3.1.2 Profile of the case company

The company is a structural steel and steel parts design, manufacturing, and installation company. The company's facility located in Turkey has 12,000 tons per shift annual production capacity and can make three shifts, when it is required. A wide range of buildings including offshore structures, heavy and light industry buildings, bridges, maritime structures, energy and airport structures as well as shipyards are amongst the projects the company has acknowledged in Turkey and abroad.

The company is an integrated organization that is its core competence. They integrate design, manufacturing, transportation and installation processes in order to achieve effectiveness and efficiency. At the point when the company designs a structure, it always bears in mind how the structure will be produced, shipped and erected. As the company motto, that is ‘Building the Optimum,’ reflects, the firm puts considerable emphasis on achievement, prediction, precision and productivity during each period of the value creation chain: marketing and sales; design and engineering; production and erection processes. The firm promises to stay focused on what it calls as its “three Ps:” design with Prediction, manufacture with Precision, and install with Productivity.

Although there are many competitors of the firm in the industry, there are not so many firms that are capable of handling complex structures. Having the benefit of designing with prediction, the firm is able to minimize the problems in production and erection, so potential profit rate per unit of time of the company is maximized. If the company prefers the projects with which it is familiar, the aims of the values that are the prediction, precision and productivity can be achieved more easily. This also leads maximization of the company profit.

Despite the fact that the firm has started its activities more than fifteen years ago, just for the last two years it has confronted with the orders that exceed the capacities of the company. In addition, the same circumstance is expected to be experienced again for the current year while the current potential orders are considered. The firm aims to maximize its profit under the framework of the existing manufacturing and technical office manpower constraints. Therefore, one of the crucial objectives is to settle on the order prioritization decision that makes the profit higher when the capacity is inadequate for the incoming demand.

2.3.1.3 Profile of the decision makers

It is hard to make order acceptance among the potential orders for a structural steel manufacturing company of which capacities are inadequate for the incoming demand. Making a wrong choice may cause less profitability for the firm as a result of the capacity constraints.

The author and the thesis advisor of this study acting as DAs interacted with three managers of the firm who were situated as “decision making units” to choose the most suitable potential order. DM group consisted of the business development manager, the factory manager, and the technical office manager. The business development manager was both an industrial and a civil engineer who had been in the sector for seven years. The factory manager was an executive that had more than fifteen-year experience in the sector; moreover the technical office manager was a civil engineer that had been in the sector for fifteen years.

2.3.2 Constituents of the decision model

2.3.2.1 Potential customer orders

The firm prepares always quotations for many tenders. Thus, there were several projects (customer orders) in the pool as alternatives. In order to decide which alternatives should have beeen considered in the study, Bottom-up Method was used. The alternatives were known, so a bottom-up (alternatives-driven) approach could be appropriate (Figure 2.3).

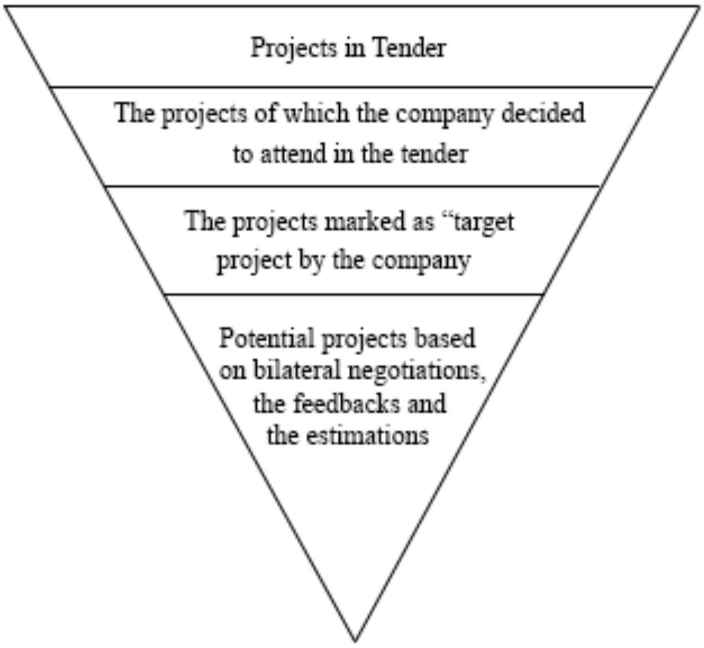

Figure 2.3 : Bottom-up method to specify potential orders.

In this study, the potential projects stated in Table 2.2 were specified as alternatives, which the company could be awarded when bilateral negotiations, the feedbacks, and the estimations were considered, were taken into account. The alternatives shown in Table 2.2 were the potential project orders that should have been exposed to selection by the firm under consideration. Figure 2.4 presents the location of these alternatives on a map.

Table 2.2 : Potential customer orders.

Customer Order	Foreign/Domestic	Project Type
Water sports center in Istanbul	Domestic	Sport Facility
Factory in Karachi, Pakistan	Foreign	Heavy and Light
Shopping Center in Sakarya	Domestic	Shopping Mall
Compressor Station in Eskisehir	Domestic	Energy
Administrative Building in Bursa	Domestic	Commercial
Housing Project in Algiers, Algeria	Foreign	Retail
City Hall Project in Lazika, Georgia	Foreign	Commercial

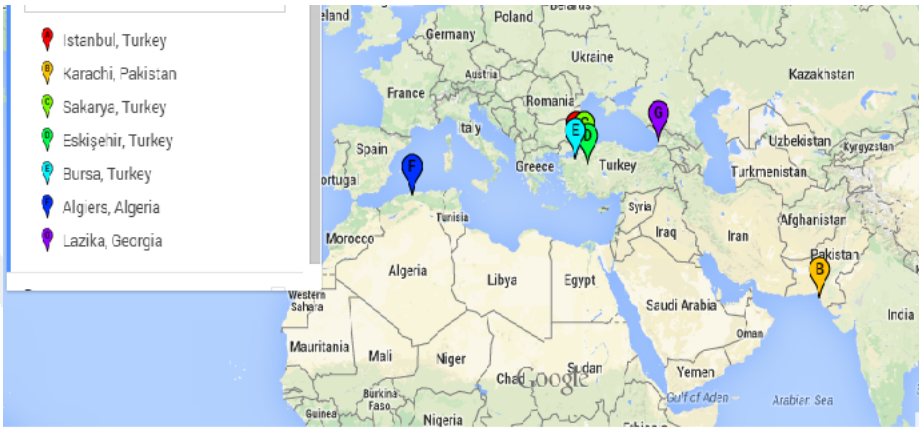

Figure 2.4 : Locations of the potential projects.

2.3.2.2 Evaluation criteria

As previously mentioned in Structuring the Problem at Section 2.2.1.1, to assess potential orders regarded as alternatives, there were several factors that could be indicated as criteria. The following criteria, which were explained in detail at Section 2.1.4, were obtained:

- Potential profit rate per unit of time
- Compatibility of potential order with the available capacity
- Level of potential future order with higher profit
- Customer credit of future business opportunity
- Negotiability level of production schedule for the order

The managers of the company reviewed and justified these criteria. So these five criteria were used at the customer order prioritization decision of that firm.

2.3.2.3 Decision model

Creating the model process should fulfill two requirements which are expressive power and usability. Every model should keep a balance between these two requirements. This balance is considered through creating the model process. There are 3 types of decision models: Normative, descriptive and composition of these two types, constructive model. The Normative Model answers the question, how decisions should be made according to a set of assumptions and standards. The Descriptive Models refers to how people actually behave. The decision model of the study was constructive model, which considered both of normative and descriptive.

All of the performance values measured by ratio scales. Ratio scales has the highest level meaning between measurement types and is the most suitable measurement type for the decision model.

After revealing a cluster of criteria and a cluster of alternatives, as a further stage of structuring phase, DMs were requested by DAs to specify the relations (effects) among criteria and alternatives. Based on the interviews with the managers, it was understood that criteria were affected by alternatives as in a typical multi criteria decision problem. Nevertheless, alternatives were also affected by criteria in this decision problem. The effect of criteria on alternatives and the effect of alternatives on criteria were pointed as outer dependence. As there was an interconnection between the set of criteria and the set of alternatives, feedback relation existed as stated at Figure 2.5.

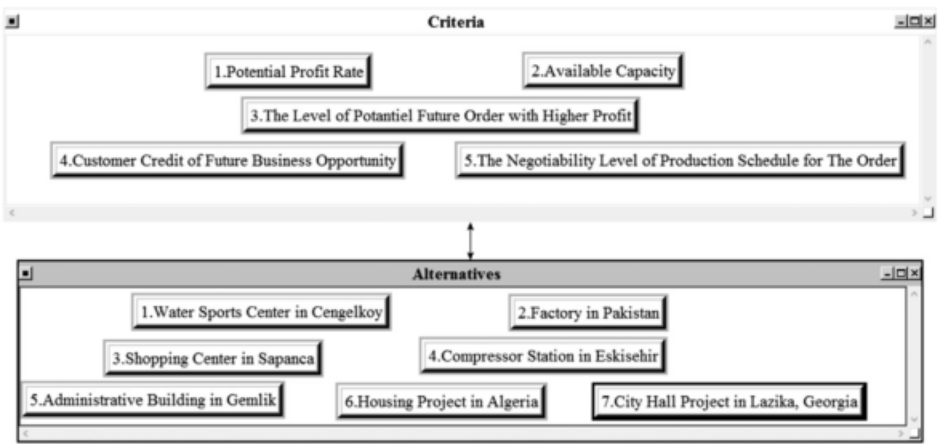

Figure 2.5 : The decision model.

Creating clusters and differentiated them from each other was a definite process for the model. The model included three clusters according to their purposes. First one was Goal Cluster and included only "To choose the most profitable projects under the limited capacity of the firm." node. Criteria Cluster was the second one and included the criteria that were potential profit rate per unit of time, compatibility of potential order with the available capacity, level of potential future order with higher profit, customer credit of future business opportunity and the negotiability level of production schedule for the order. The third one was the Alternatives Cluster and includes the alternative projects which the model would recommend one of.

The next step was constructing the pairwise comparison matrices. To understand the model one should examine the pairwise comparisons. All the uncollected data version of pairwise comparisons was listed in Figure 2.6, Figure 2.7, and Figure 2.8.

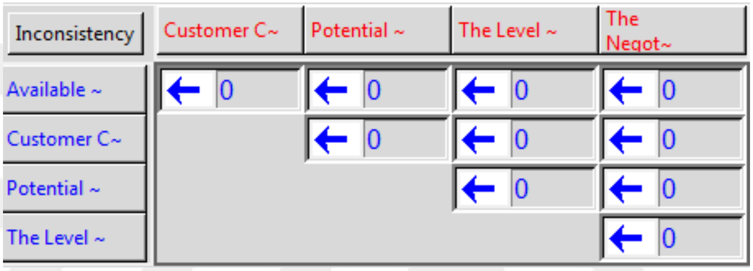

Figure 2.6 : Node comparisons matrix with respect to Selecting Most Suitable Project.

Figure 2.7 : Node comparisons matrix with respect to Criteria Nodes.

All of the Criteria Nodes had the same pairwise comparisons matrix appearance. These matrices would differ from others after filling the survey.

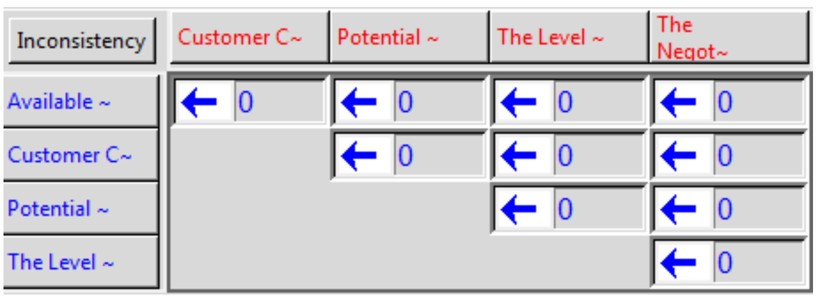

Figure 2.8 : Node comparisons matrix with respect to Alternatives Nodes.

All of the Alternative Nodes had the same pairwise comparisons matrix appearance. These matrices also would differ from others after filling the survey.

2.3.3 Assessing judgments

In accordance with ANP methodology, the managers were requested to compare the alternative pairs based on their influence on each criterion they affect. Correspondingly, DMs compared the criteria pairs based on their influence on each alternative they affect. In other words, the managers were posed pairwise comparison questions for eliciting their judgments with a question using a nine-point scale as mentioned in Basic Steps of ANP at Section 2.2.2.3.

A pairwise comparison questionnaire survey was conducted to evaluate the judgments of the managers for all possible pairs of elements. Managers were visited and explained for the research methodology face-to-face. There were two sorts of questions in the survey form: “with respect to a criterion which of the following projects are more preferred?” and “with respect to an alternative which of the following criteria affects it more?” For each criterion, 21 pairwise comparison questions were posed whilst for each alternative, this number is 10. The whole questionnaire, given in Appendix A, was comprised of 175 questions.

Managers selected an alternative or a criterion for each pair and denoted a figure at the scale to represent the degree of dominance of the chosen alternative/criteria on the other one with respect to affected aim/alternative/criterion. Consistency ratios of pairwise comparisons, which is given in Table 2.3, were calculated and it was discovered that none of the managers were inconsistent beyond 10 percent that implied that the step of eliciting judgements were completed in one session and there was no need for reiteration.

Table 2.3 : Consistency ratios of pairwise comparisons of DMs.

Comparison Of	With Respect to the Effect On	Business Dev. Manager	Factory Manager	Technical Office Manager
Criteria	Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration	8.66%	9.09%	9.32%
Alternatives	Potential profit rate per unit of time	8.02%	3.57%	9.51%
Alternatives	Compatibility of potential order with the available capacity	4.59%	5.65%	8.35%
Alternatives	Level of potential future order with higher profit	7.84%	9.46%	7.35%
Alternatives	Customer credit of future business opportunity	7.68%	8.68%	8.35%
Alternatives	Negotiability level of production schedule for the order	7.83%	6.55%	7.15%
Criteria	Water Sport Center in Cengelkoy	5.87%	8.76%	8.15%
Criteria	Shopping Center in Sapanca	4.68%	5.46%	9.15%
Criteria	Administrative Building in Gemlik	8.35%	3.35%	6.35%
Criteria	Factory in Pakistan	8.75%	8.54%	8.02%
Criteria	Compressor Station in Eskisehir	3.10%	2.86%	4.01%
Criteria	Housing Project in Algeria	8.15%	6.46%	5.21%
Criteria	City Hall Project in Lazika, Georgia	8.75%	7.65%	7.35%
Criteria	Selecting the most suitable order under limited workforce and Manufacturing capacities for the company under consideration	8.66%	9.09%	9.32%
Alternatives	Potential profit rate per unit of time	8.02%	3.57%	9.51%
Alternatives	Compatibility of potential order with the available capacity	4.59%	5.65%	8.35%
Alternatives	Level of potential future order with higher profit	7.84%	9.46%	7.35%
Alternatives	Customer credit of future business opportunity	7.68%	8.68%	8.35%

Table 2.3 (continued) : Consistency ratios of pairwise comparisons of DMs.

Comparison Of	With Respect to the Effect On	Business Dev. Manager	Factory Manager	Technical Office Manager
Alternatives	Negotiability level of production schedule for the order	7.83%	6.55%	7.15%
Criteria	Water Sport Center in Cengelkoy	5.87%	8.76%	8.15%
Criteria	Shopping Center in Sapanca	4.68%	5.46%	9.15%
Criteria	Administrative Building in Gemlik	8.35%	3.35%	6.35%
Criteria	Factory in Pakistan	8.75%	8.54%	8.02%
Criteria	Compressor Station in Eskisehir	3.10%	2.86%	4.01%
Criteria	Housing Project in Algeria	8.15%	6.46%	5.21%
Criteria	City Hall Project in Lazika, Georgia	8.75%	7.65%	7.35%

The elicited judgments of the managers were aggregated at the next step. DAs compute the geometric means of all paired comparison judgments for each question to reveal the aggregated group judgments (Appendix B).

2.3.4 Data analysis

At the final phase of the decision making process, Super Decisions software was utilized to reveal the relative priorities of the criteria and the alternatives by using the aggregated judgments. For this reason, the aggregated elicited judgements were put into the pairwise comparison matrices produced by the software.

Super Decisions processed the eigenvectors of the alternatives with respect to criteria as well as the eigenvectors of the criteria with respect to alternatives for each pairwise comparison matrix. At that point, the software stated each eigenvector to the column representing the affected element and the rows representing the affecting ones to form the super-matrix of the decision model (Appendix C).

Table 2.4 and Table 2.5 show the output of the decision framework for the customer order prioritization.

Table 2.4 : Priorities of alternatives.

Potential Projects	Priority
Administrative Building in Gemlik	21.64%
Shopping Center in Sapanca	20.82%
Housing Project in Algeria	15.68%
Factory in Pakistan	12.68%
Water Sports Center in Cengelkoy	11.01%
City Hall Project in Lazika, Georgia	10.37%
Compressor Station in Eskisehir	7.81%

Table 2.5 : Priorities of criteria.

Evaluation Criteria	Priority
Customer credit of future business opportunity	35.48%
Potential profit rate per unit of time	26.77%
The negotiability level of production schedule for the order	14.38%
The level of potential future order with higher profit	12.11%
The compatibility of potential order with the available capacity	11.26%

Selection between the alternatives is made by solving a knapsack problem in which the priorities of the criteria are supposed to be the coefficients of the objective function and there is a constraint which considers 5,700 tons company's design and production capacity.

Table 2.6 : Knapsack problem.

Variables	Potential Projects	Weight	Project Quantity (tons)
x_1	Administrative Building in Gemlik	21.64	1,213
x_2	Shopping Center in Sapanca	20.82	2,222
x_3	Housing Project in Algeria	15.68	2,272
x_4	Factory in Pakistan	12.68	2,065
x_5	Water Sports Center in Cengelkoy	11.01	3,406
x_6	City Hall Project in Lazika, Georgia	10.37	2,657
x_7	Compressor Station in Eskisehir	7.81	2,509

$$\max z = 21{,}64x_1 + 20.82x_2 + 15.68x_3 + 12.68x_4 + 11.01x_5 + 10.37x_6 + 7.81x_7 \tag{2.1}$$

$$1212x_1 + 2222x_2 + 2272x_3 + 2065x_4 + 3406x_5 + 2657x_6 + 2509x_7 \leq 5700 \tag{2.2}$$

$$x_i = 0 \; or \; 1 \qquad\qquad i = 1,2,\dots,7 \tag{2.3}$$

The best solution is found as x_1, x_2 and x_4 of which objective function value is 98,695.56 and the total quantity is 5,500 tons. This solution is presented to the structural steel manufacturing company's decision makers who are business development, technical office and factory managers and they were recommended to choose projects in accordance with the solution. The company under consideration also decided to choose the first, the second, and the fourth customer orders.

3. FACILITY LAYOUT

3.1 Literature Review

One of the classical and crucial problems in manufacturing system is Facility Layout Problem (Zha et al., 2017). Facility Layout is the configuration of anything needed for production such as workstations, departments, warehouses, machines, equipment, and etc. (Heragu, 1997, Kang et al., 2017) and it has significant effects on production costs, work in process, delivery lead times, and productivity (Drira et al., 2007). A proper facility layout design provides overall efficiency of operations and also decreases the total operating expenses until 50% (Tompkins et al., 1996). Unfortunately, the facility location problems are very complex and often known as non-polynomial hard (NP-hard). (Garey and Johnson, 1979). NP-hard problems are unsolvable in polynomial time (Kusiak, 1990). There are not accurate mathematical solutions for such problems. The complexity of such problems increases exponentially with the number of machines. For example, a manufacturing system consisting of N machines will comprise a solution space with the size N. Theoretically the problem is solvable by testing all possibilities (i.e., random searching) but practical experience presents the human or the computer capabilities are fast exceeded in such a kind of solution strategy. The number of possible solutions is equal to the number of permutations of N elements for facility layout design problems. When N is large, it is difficult, if not impossible, to find the optimal solution within a reasonable time, even with support of a powerful computer. With today's modern computers' computation power it is possible to search for the optimum solution by examining the total space of solutions somewhere up to the dimensions of space 10. For larger dimensions it is necessary to use sophisticated solving methods (Ficko et al., 2004).

3.1.1 Factory characteristics

Factory characteristics impacting facility design can be stated as follows: the production variety and volume, the material handling system chosen, the different possible flows allowed for parts, the number of floors on which the machines can be assigned, the facility shapes and the pick-up and drop-off locations (Drira et al., 2007).

3.1.1.1 Product variety and volume

Product variety and volume form a basis for facility layout design. According to the existing articles, there are four organization types: fixed product layout, process layout, product layout, and cellular layout (Dilworth, 1996).

i. Fixed product layout: A production technique is used to assemble products that are too large, bulky, or fragile to safely or effectively move to allocation for completion such as ships or aircrafts production. In a fixed position layout, workers, supplies, and equipment are brought to the site where the product will be assembled, rather than the product being moved through an assembly line or set of assembly stations.

ii. Process layout: The workstations and machinery are not arranged according to a particular production sequence. Instead, there is an assembly of similar operations or similar machinery in each workstation in order to produce a wide variety of products.

iii. Product layout: This organization that is also named as assembly lines are suitable for high production volumes and a low variety of products.

iv. Cellular layout: The similar parts are produced in the cells that consist of grouped machines.

3.1.1.2 Facility shapes and dimensions

The facility shapes are generally separated into two shapes: regular that is generally rectangular shaped (Kim and Kim, 2000); and irregular that is generally polygon containing at least 270° angle (Lee et al., 2001).

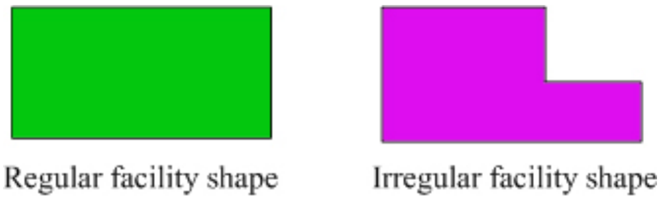

Figure 3.1 : Regular and irregular facility shapes.

Facilities are called "fixed or rigid blocks" if it defines with a fixed length (L_i) and fixed with (W_i). On the other hand facilities can be defined by its aspect ratio: a_i=L_i/W_i; an upper bound a_{iu} and a lower bound a_{il} such that $a_{il} < a_i < a_{iu}$ (Chwif et al., 1998; Meller et al., 1999). If $a_{il} = a_i = a_{iu}$, it fits to fixed shape block case (Chwif et al., 1998).

3.1.1.3 Material handling systems

In order to deliver materials to the appropriate locations, material handling systems are used. The handling can be done by conveyors (belt, roller, wheel) or automated guided vehicles (AGVs), robots etc. (El-Baz, 2004). Tompkins et al. (1996) stated that 20-50% of production costs are posed by the handling of parts and by the arrangement of handling equipment this ratio can be reduced to 10-30%.

Depending on the type of material handling, main facility orientation can be grouped as follows: single row layout, multi-rows layout, loop layout, and open-field layout (Yang et al., 2005).

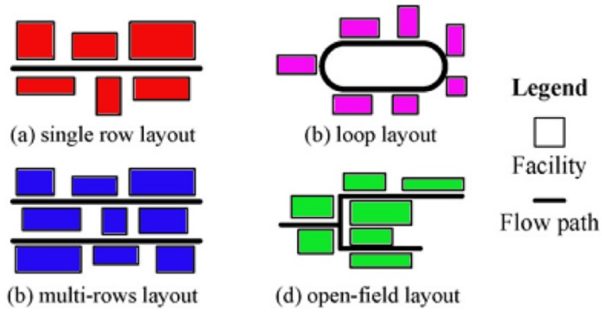

Figure 3.2 : Main facility layout depending on the type of material handling.

a) Single row layout: When the plants have to be arranged in a line, single row layout problem arises (Ficko et al., 2004; Djellab and Gourgand, 2001; Kim et al., 1996; Kumar et al., 1995). The shape of this line can be a straight, semicircular or U-shape (Hassan, 1994). The line consists of single stations that are in a straight line along a conveying system. Each station is responsible for producing one or more tasks on the partially finished product and can be a simple part of a complex system (Baybars, 1986).

b) Loop layout: If it is needed to position facilities for candidate locations in a closed ring network, loop layout problem occurs (Nearchou, 2006; Chaieb, 2002; Potts and Whitehead, 2001; Cheng et al., 1996).

c) Multi-rows layout: If there are several lines, multi-rows layout problem occurs (Hassan, 1994).

d) Open-field layout: If there are no restrictions or constraints that would push the layout to a line or loop system, open-field layout system that allows freedom in design is used (Yang et al., 2005).

3.1.1.4 Number of floors in the facility

If the land is expensive or the existing land is not suitable to expand; it can be relevant to locate the factory on several floors. In this case, parts can be move in two dimensions: horizontal and vertical. A vertical transportation vehicle such as elevator should be used for vertical transportation. In multi-layout system, both the location on the floor and the levels should be designed (Kochhar and Heragu, 1998).

3.1.1.5 Backtracking and by passing

The flow of the parts is affected by backtracking and by passing movements. The backtracking is the movement of a part from its position to a preceding one in the flow arrangement (Zhou, 1998; Braglia, 1996; Kouvelis and Chiang, 1992). Backtraking should be minimized (Zhou, 1998).

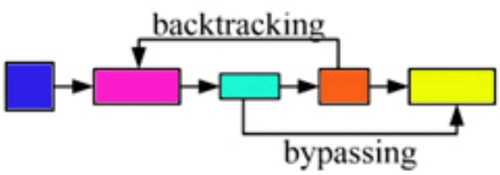

Figure 3.3 : Backtracking and bypassing.

Bypassing is the movement of a part from its position to another one by skipping the ones in between in the flow arrangement (Chen et al. 2001).

3.1.1.6 Pick-up and drop-off locations

While the location that parts enter the facilities is called as pick-up; the location that parts leave is called drop-off location. Even though they can be specified potentially at various places (Kim and Kim, 2000); some researches limited their possible locations in order to minimize the complexity (Rajasekharan, 1998; Das, 1993; Welgama et al., 1993).

3.1.2 Static and dynamic layout systems

In most articles, facility layouts are considered as static in which the key data about the workshop and what it is intended to produce are assumed to remain constant enough over a long period of time (Drira et al., 2007). For static systems, the facility layout problem is solved for a single period, when the interdepartmental flow is almost constant from period to period. In such cases, layout design considers the assignment of ‘m’ facilities to ‘m’ discrete locations with the minimizing the assignment cost objective. The assignment cost is defined as the sum of the product of flow of materials between the facilities, the distances between their locations and the cost of installation (Pillai et al., 2011). Respectable amount of research has been made to static layout problems with exact, heuristic, meta-heuristic and hybrid solution approaches. Some researchers (Bock & Hoberg, 2007; Chan et al., 2002; Foulds et al., 1998; Tang & Abdel-Malek, 1996; Tam & Li, 1991) propose heuristic methods to solve static facility layout problems. They took care about various constraints like forbidden areas, equal and unequal areas, aisles and barriers within the layout like existing walls or columns. On the other hand, some researchers (El-Baz, 2004; Hu and Wang, 2004; Mak et al., 1998; Wilhelm and Ward, 1987) have undertook the static facility layout problems with the meta-heuristics such as simulated annealing, genetic algorithm to solve the large size layout problems. The static facility layout problems are also systematized with multiple objectives like combining both quantitative and qualitative factors and they are solved with heuristic, metaheuristics, or hybrid approaches by some researchers (Khilwani et al., 2008; Ertay et al., 2006; Tuzkaya et al., 2005; Sha and Chen, 2001; Islier, 1998; Meller and Gau, 1996; Raoot and Rakshit, 1993; Catherine and Tothero, 1992; Heragu and Kusiak, 1990.

In today's dynamic world, the factories should be able to react quickly according to the changes in demand, production volume and product mix. Therefore, dynamic layout problems that consider possible changes in the material handling flow over multiple periods are considered (Meng et al., 2004; Braglia et al., 2003; Kouvelis et al., 1992). The dynamic facility layout problem assumes different flow matrices in the different planning horizon periods and achieves at best layouts for the whole planning horizon. Adaptive, flexible, agile and robust approaches are used to solve the dynamic facility layout problems (Pillai et al., 2011).

3.2 Formulation of Layout Problems

The formulation of static and dynamic layout problems can depend on different methods, that include graph theory (Kim and Kim, 1995; Leung, 1992; Proth, 1992) or neural network (Tsuchiya et al., 1996). These methods are usually used to propose solutions to the layout problems, which many researchers remark as optimization problems, with either single or multiple objectives. Based on the formulation type (discrete or continuous), the most commonly used formulations stated in the literature are Quadratic Assignment Problems (QAP) or Mixed Integer Programming (MIP) problems. On the other hand, a couple of authors have argued that the available data could not be completely known and have proposed fuzzy formulation (Drira et al., 2007).

3.2.1 Formulation of QAP

One of the most difficult classical combinatorial optimization problems is QAP and it is well known for its diverse applications.

Koopmans and Beckmann (1957) introduced QAP in 1957 as a mathematical model for the location of indivisible economical activities. The formal definition of QAP is given as "There are a set of n workstations to be assigned to n locations, with the cost being proportional to the flow between workstations multiplied by the distances between the locations. The costs for placing the workstations at their respective locations are also added to get the total cost. The objective is to find an assignment such that the total cost is minimized."

The layout representation in QAP is discrete as given in Figure 3.4. The plant site is divided into rectangular blocks that have the same area and shape. In this system, each block is assigned to a workstation. If workstations have unequal areas, they can occupy different blocks (Wang, et al., 2005).

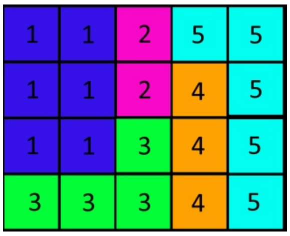

Figure 3.4 : Discrete layout representation in QAP.

Koopmans and Beckmann (1957) formulated QAP as stated in equation 3.1 and 3.2.

$$\min_{x \in X} \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} f_{ik}\, d_{jl} x_{ij} x_{kl} + \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij} \tag{3.1}$$

$$where\ X = \left\{ x \,\middle|\, \sum_{j=1}^{n} x_{ij} = 1 \quad i \epsilon N, \sum_{i=1}^{n} x_{ij} = 1 \quad j \epsilon N, x_{ij} \epsilon \{0,1\} \quad i, j \epsilon N \right\} \tag{3.2}$$

and f_{ik} is the flow between workstations i and k, d_{jl} is the distance between locations j and l, and c_{ij} is the cost of placing workstation i at location j. The variable $x_{ij} = 1$ if workstation i is assigned to location j, otherwise, $x_{ij} = 0$ and $N = \{1, 2, \ldots, n\}$. With no loss of generality it can be assumed that $c_{ij} = 0$ and as a result the linear term in (3.1) can be omitted.

The QAP is one of the well-known formulations of the layout problems. Equal size workstations are assumed in these problems (Baykasoglu and Gindy, 2001; Lacksonen and Enscore, 1993) and each location is assigned to only one workstation at each period, and exactly one workstation is assigned to each location at each period (Baykasoglu and Gindy, 2001; McKendall, et al., 2006). Budget constraints can be added to execute the reconfiguration of workstations on the floor plant (Balakrishnan, et al., 1992; Baykasoglu, et al., 2006). A matter of fact that, the rearrangement costs must not exceed a certain level of the budget.

The QAP formulation is not sufficient to show the exact position of facilities in the plant site and is not able to formulate appropriately specific constraints as the orientation of workstations, pick-up and drop-off points or clearance between workstations. In such situations, a mixed integer programming formulation is stated to be more relevant by several authors (Dunker, et al., 2005; Lacksonsen, 1997; Das, 1993).

3.2.2 Formulation of MIP

A mixed-integer programming (MIP) problem is one where some of the decision variables are constrained to be integer values (i.e. whole numbers such as -1, 0, 1, 2, etc.) at the optimal solution. An important special case is a decision variable x_1 that must be either 0 or 1 at the solution. Such variables are called 0-1 or binary integer variables. Integer variables make an optimization problem non-convex, and therefore far more difficult to solve. Memory and solution time may rise exponentially as you add more integer variables (Url-5).

MIP theory and practice has been significantly developed and is now an indispensable tool in business and engineering (Spielberg and Spielberg, 2005; Jünger et al., 2010; Lee, 2008). There are two reasons for the success of MIP (i) Linear Programming (LP) based solvers and (ii) the modelling flexibility of MIP. There are several extremely effective state of the art solvers (Url-6, Url-7, Url-8, Url-9) that incorporate many advanced techniques [Achterberg, 2007, Adams and Forrester, 2005, Bixby and Rothberg, 2007, Johnson et al., 2000, Bixby et al., 2004).

The layout representation of MIP is continual as shown in Figure 3.5.

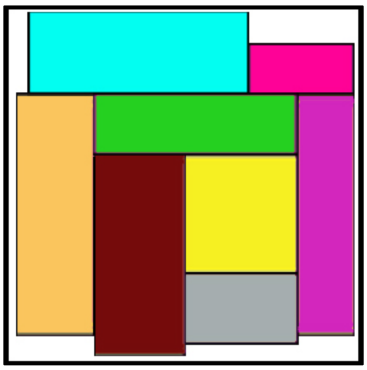

Figure 3.5 : Continuous layout representation in MIP.

The workstations in MIP system are located anywhere within the layout and they should not overlap each other (Dunker, et al., 2005; Meller, et al., 1999; Das, 1993).

The workstations in the layout are placed either by their centroid coordinates (x_i, y_i), half length l_i and half width w_i or by the coordinates of bottom-left corner, length L_i and width W_i of the workstation. For instance, the distance between two workstations can be expressed through the rectilinear norm (Chwif, et al., 1998) stated in equation 3.3.

$$d_{ij}\left((x_i, y_i), (x_j, y_j)\right) = |x_i - x_j| + |y_i - y_j| \tag{3.3}$$

Although there are many constraints according the problem on hand, the most common constraints in the MIP system can be specified as: nonoverlapping of workstations, area constraint, pick-up and drop off constraints, clearance between workstations.

A very crucial issue in MIP system is that the workstations must not overlap. This constraint can be expressed with two conditions stated in equation 3.4 and 3.5 (Welgama and Gibson, 1993).

$$(x_{jt} - x_{ib}), (x_{jb} - x_{it}) \geq 0 \tag{3.4}$$

$$(y_{jt} - y_{ib}), (y_{jb} - y_{it}) \geq 0 \tag{3.5}$$

Where (x_{it}, y_{it}) and (x_{ib}, y_{ib}) are the top-left and the bottom right corners of the facility i and (x_{jt}, y_{jt}) and (x_{jb}, y_{jb}) are the top-left and the bottom right corners of the facility j.

On the other hand, an overlap area O_{ij} between two workstations is defined to gather non-overlapping of facilities by Mir and Imam (2001) as equation 3.6 and 3.7:

$$\text{Minimize objective function} \tag{3.6}$$

$$\text{Subject to } O_{ij} \leq 0 \tag{3.7}$$

The area constraint that is the total available area must be superior or equal the sum of all workstation areas should be specified. Other resources or buffers that are required for operating the machine should be taken into account in the needed workstation area for each machine. The solution of the problem should give a result in accordance with predefined shapes of both machines and plant layout (Lacksonen, 1997).

The pick-up and drop-off points can be inducing constraints in MIP system (Yang et al., 2005; Kim and Kim, 2000; Welgama and Gibson, 1993). In addition, some authors are specified pick-up and drop-off points in a specific problem (Aiello et al., 2002; Kim and Kim, 1999; Chittratanawat and Noble, 1999).

Moreover, Heragu and Kusiak (1991) and Braglia (1996) have used clearance between workstations as a constant value. On the other study of Heragu and Kusiak (1988) it has been included in the workstation size. Izadinia (2016) proposed a mixed integer programming model to generate a robust solution for multi-floor layout problem.

There are also few studies that focus on dynamic layout problems using a MIP formulation. For instance, Dunker et al. (2005) has specified unequal size layout problems in a dynamic environment and assumed that the workstation sizes vary form one period to another.

3.3 Resolution Approaches

Exact methods and heuristic methods that are shown in Figure 3.6 are used in resolution of facility layout problems.

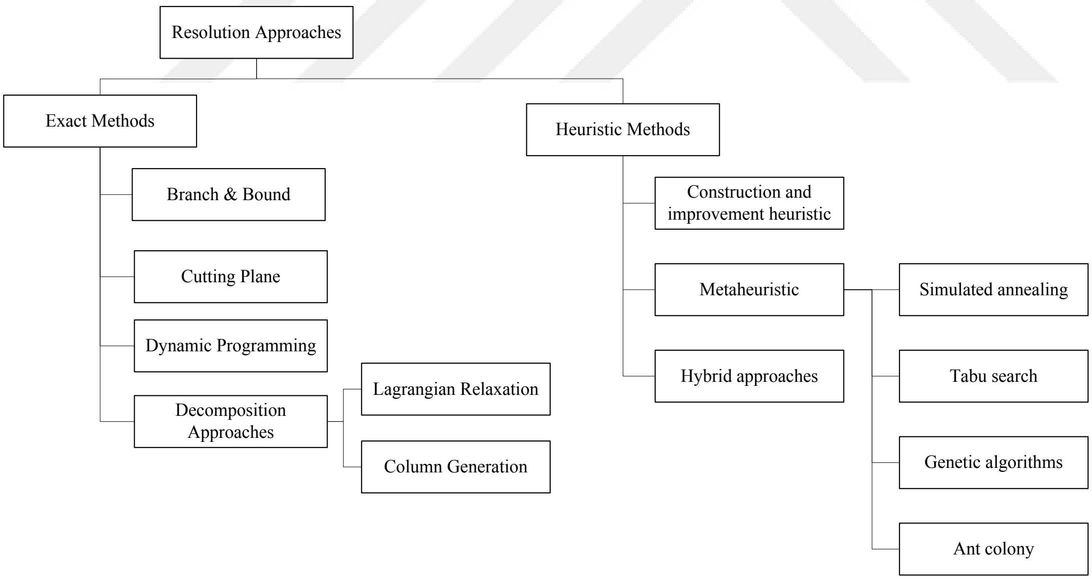

Figure 3.6 : Resolution of facility layout problems.

3.3.1 Exact methods

3.3.1.1 Branch and bound

Branch and bound algorithm was developed by Kouvelis and Kim in 1992 for the unidirectional loop layout problem. Later on in 1999, Meller, et al. applied branch and bound algorithm mentality to solve a general facility layout problem which uses a class of inequalities to expand the range of the solvable problems.

A block facility layout problem including pick-up and drop-off locations was considered by Kim and Kim in 1999. In their study, they developed a branch and bound algorithm in order to place the pick-up and drop-off points of each facility for a pre-specified plant layout. Although this algorithm is useful for large size problems, it is not able to solve both the block problem and pick-up & drop-off points.

Because MIP problems are non-convex, they must be solved by some kind of systematic and potentially exhaustive search. The most common method for solving these problems is Branch and Bound which starts by finding the optimal solution to the "relaxation" of the problem without the integer constraints (via standard linear or nonlinear optimization methods). If the decision variables with integer constraints have integer values in that solution, then no further work is needed. If one or more integer variables have non-integral solutions, the Branch and Bound method chooses one such variable and "branches," developing two new sub-problems where the value of that variable is more tightly constrained. These sub-problems are solved and the process is repeated, till a solution that satisfies all of the integer constraints is gathered (Url-5).

3.3.1.2 Cutting plane

Cutting plane methods are exact algorithms used for integer programming problems. They are computationally very, especially when they combined with a branch and bound algorithm in a branch and cut framework. These algorithms used by solving a sequence of linear programming relaxations of the integer-programming problem. The relaxations are gradually improved to gather better approximations to the integer-programming problem, at least in the neighborhood of the optimal solution. For hard instances that cannot be solved optimality, these algorithms can develop approximations to the optimal solution in moderate computation times, with guarantees on the distance to optimality (Aziz, 2012).

3.3.1.3 Dynamic programming

A dynamic programming method was developed by Rosenblatt (1986) to solve the dynamic programming method problem of locating equal size facilities. But their system is able to give optimal solution for just only small scale problem instances.

Exact approaches are usually not suitable for large size problems therefore some researchers have developed heuristics and metaheuristics methods to solve large-scale problems.

3.3.1.4 Decomposition approaches

In decomposition approaches, the original problem is separated into multiple, easier to-solve sub problems. A solution of the original problem can be acquired by sequentially or iteratively solving the resulting sub problems. Specifically in the context of large, complex optimization problems, decompositions provide a number of advantages. When the original problem is separated into smaller sub problems, each sub problem could be solved by efficient, dedicated procedures that can employ different optimization techniques independently. Likewise, various optimization problems usually share some common component solvable by the same algorithm; isolating this component through decomposition could facilitate efficient reuse of code. Different structural properties of the optimization problem can be considered by decomposing a problem. The latter observation is used to derive strong bounds on the optimal solutions. There are examples in literature where problems are decomposed through Column Generation; the resulting decomposition often yields stronger bounds than any of the bounds obtainable through alternative MIP models formulated over the entire problem. As a matter of fact, many of these MIP formulations suffer from large numbers of conditional constraints, resulting in weak Linear Programming relaxations and consequently weak bounds (Kinable, 2014).

3.3.2 Heuristic approaches

Heuristic approaches are used to build a solution or to improve an existing solution.

3.3.2.1 Construction and improvement heuristics

Construction heuristics examples are SHAPE (Hassan, et al., 1986), COFAD (Tompkins and Reed, 1976), CORELAP (Lee and Moore, 1967) and ALDEP (Seehof and Evans, 1967).

Improvement heuristics examples are DISCON (Drezner, 1987), FRAT (Khalil, 1973), and CRAFT (Armour and Buffa, 1963).

3.3.2.2 Metaheuristics

Metaheuristics methods can be specified as local search methods (Tabu search and simulated annealing) and evolutionary approaches (genetic and colony algorithms).

Tabu search

Tabu search algorithm is developed by Chiang and Kouvelis in 1996 to solve facility layout problem, which contains all basic features of tabu search framework. They used a sequential neighborhood focused on the exchange of location of two facilities and included a long run memory structure, a dynamic tabu list size, an intensification criteria and diversification strategies.

Simulated annealing

Chwif, et al., (1998) modelled a simulated annealing algorithm to solve the facility layout problem with aspect ratio facilities sizes. The first neighborhood procedure modelled was a pairwise exchange between facilities. The second one was random moves on the facility layout at the upwards, downwards, leftwards and rightward directions.

Two simulated annealing approaches for a dynamic facility layout problem with equal size facilities are developed by Mc Kendall, et al. (2006).

Genetic algorithms

Genetic algorithms are supposed to be more popular in solving facility layout problems (Pierreval, et al., 2003). Genetic algorithms are used in many static layout problems such as Wang, et al., 2005; Dunker, et al., 2003; Wu and Appleton, 2002; Azadivar and Wang, 2000; Tam and Chan, 1998; Mak, et al., 1998) and in many dynamic layout problems such as Dunker, et al., 2005; Balakrishnan, et al., 2003; Balakrishnan and Cheng, 2000).

Genetic algorithms can be used in the solution of MIP problems. They randomly generate candidate solutions that satisfy the integer constraints. Such initial solutions are usually far from optimal, but these methods then transform existing solutions into new candidate solutions, through methods such as integer- or permutation-preserving mutation and crossover, that continue to satisfy the integer constraints, but may have better objective values. This process is repeated until a sufficiently "good solution" is found. Generally, these methods are not able to "prove optimality" of the solution (Url-5).

Ant colony

In 2005 Solimanpur, et al. developped and ant algorithm to solve layout problem for a sequence dependent single row machine layout problem.

In 2006, Baykasoglu et al. developed an ant colony algorithm to solve the unconstrained and budget constrained dynamic layout problems. They also proposed an improvement procedure that considers random swaps of two facilities in a randomly-selected period.

3.3.2.3 Hybrid approaches

Some researchers used hybrid metaheuristic approaches to solve facility layout problems.

For instance, Mir and Imam (2001) proposed a hybrid approach for unequal area facilities. First, they used simulated annealing algorithm to find an initial solution. Then, an analytical search technique in a multi-phase optimization process was used to find optimal facility locations.

Mahdi, et al. developed a hybrid approach to minimize the material handling cost in 1998. They proposed a simulated annealing algorithm to solve the geometry problem, a genetic algorithm to decide which material handling system will be used and an exact method for minimizing the total material handling utilization cost.

Many other researchers used hybrid approaches for facility layout problems such as: McKendall and Shang (2006); Balakrishnani et al. (2003), Lee and Lee (2002), Urban (1993), Rosenblatt (1986), Armour and Buffa (1963).

3.4 AMPL

AMPL (A Modeling Language for Mathematical Programming) is an advanced modeling tool that supports the whole optimization modeling lifecycle: development, testing, deployment, and maintenance. By utilizing a high-level representation, which represents optimization models in the same ways people consider them, AMPL provides rapid development and reliable results. AMPL integrates a modeling language, a command language and a scripting language. Modelling language consists of describing optimization data, variables, objectives and constraints, while a command language covers browsing models and analyzing results. Moreover, the scripting language consists of gathering and manipulating data and implementing iterative optimization schemes (Url-3).

The full sequence of using AMPL is defined in Figure 3.7.

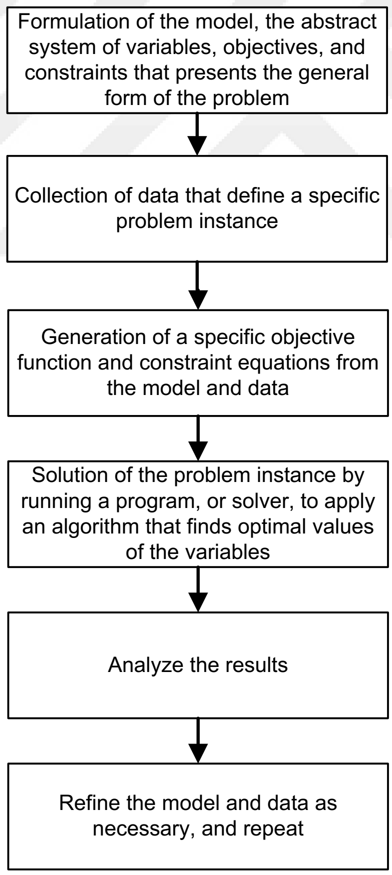

Figure 3.7 : The full sequence of using AMPL.

In modelling and solving the problems, hand solution is more time-consuming, costly and often error-prone procedure than using mathematical programs. The formulation and generation phases of modeling are relatively a straightforward process for people. Therefore it is better to use mathematical programs to convert "modeler's form" to the "algorithm's form" (Fourer et al., 2002).

3.5 Solvers

While optimization problems from models and data are created and results for analysis are retrieved by AMPL, optimal solutions are computed by solvers. All solvers of AMPL is given in Table 3.1.

Table 3.1 : All solvers for AMPL.

Solver	Algorithm Type
ACRS	Nonlinear global
ALGENCAN	Nonlinear
BARON	Global nonlinear
BLMVM	Nonlinear, bounded-variable
Bonmin	Integer nonlinear
BPMPD	Linear (interior)
CBC	Linear (simplex), Integer linear
CONDOR	Nonlinear, nondifferentiable
CONOPT	Nonlinear
Couenne	Integer nonlinear
CPLEX	Linear (simplex), Linear (interior), Network, Quadratic Integer linear, Integer quadratic
DONLP2	Nonlinear
FilMINT	Integer nonlinear
FILTER /	Nonlinear
MINLP	Integer nonlinear
FortMP	Linear (simplex), Linear (interior), Quadratic, Integer linear, Integer quadratic
FSQP	Nonlinear
Gecode	Constraint programming
Gurobi	Linear (simplex), Linear (interior), Quadratic, Integer linear, Integer quadratic
IBM ILOG CPLEX CP Optimizer	Constraint programming
IPOPT	Nonlinear
JaCoP	Constraint programming
KNITRO	Nonlinear
LANCELOT	Nonlinear
L-BFGS-B	Nonlinear bounded-variable
LGO	Nonlinear global
LocalSolver	Integer nonlinear
LOQO	Linear (interior), Quadratic, Nonlinear
LP_SOLVE	Linear (simplex), Integer linear

Table 3.1 (continued) : All solvers for AMPL.

Solver	Algorithm Type
MINLP	Integer nonlinear
MINOS	Linear (simplex), Nonlinear
MINTO	Linear (simplex), Integer linear
MOSEK	Linear (simplex), Linear (interior), Quadratic, nonlinear convex, Integer linear, integer quadratic
NPSOL	Nonlinear
NSIPS	Nonlinear semi-infinite
OOQP	Linear, Quadratic convex
PATH	Complementarity
PCx	Linear (interior)
PENNON	Nonlinear
SNOPT	Nonlinear
SOPT	Linear (simplex), Quadratic, Nonlinear convex, Integer linear
Sulum	Linear (simplex), Integer linear
TRON	Nonlinear bounded-variable
WSAT(OIP)	Integer linear constraints
XA	Linear (simplex), Integer linear
XLSOL LS-XLSOL	Linear (simplex), Quadratic, Integer linear
Xpress	Linear (simplex), Linear (interior) Quadratic, Integer linear

3.6 Real Life Case Study

3.6.1 Problem definition

The same structural steel manufacturing company that is considered as a case study for the customer order prioritization problem in Section 2.3 is taken into account for the case study of facility layout design of selected projects.

According to the results gathered in Section 2.3, the structural steel manufacturing company was recommended to choose Administrative Building in Gemlik, Shopping Center in Sapanca and Factory in Pakistan in accordance with the knapsack problem solution which considers the prioritizations of projects. The company under consideration also agreed on this selection. After selection of these alternatives, the facility layout design is required to manufacture these three alternatives simultaneously.

Structural steel is mostly manufactured in controlled facility environments off-site, for better precision and accurate detailing and fabrication. The different parts are grouped together as modules in the factory conditions and then installed on the construction site.

In the structural steel fabrication there is a wide variety of product mix. In addition, the manufacturing process is complex, because of the uniqueness of steel projects like power plants, shopping malls, bridges, stadiums, etc. Because of the low repetitiveness in projects and the diverse range of products, the manufacturing process is different for each project within the manufacturing facility. Therefore, the facility layout should be dynamic so layout re-design is required for each project to improve productivity.

3.6.2 Factory characteristics

The structural steel manufacturing company under consideration is suitable for "process layout" design in terms of "product variety and volume" characteristic, because there is a wide range variety of products and similar operations.

Regarding the "facility shapes an dimensions" characteristic, the shape of the facility is regular rectangular shaped and the dimensions are the manufacturing is 25 m (B_y) in width and 140 m (B_x) in length.

Depending on the "type of the material handling" characteristic, the process of the structural steel manufacturing company is suitable for "single row layout" system in which each station is responsible for producing one task on the partially finished product and is a part of a complex system.

Based on the "number of floors in the facility" characteristic, there is one floor in the facility of the structural steel manufacturing company.

There is no backtracking and by passing in the process of the structural steel manufacturing company in terms of "backtracking and by passing" characteristic.

Pick-up and drop-off locations of each workstation are suitable to consider in the required area of each workstation, based on the "pick-up and drop-off locations" characteristic.

3.6.3 Fabrication processes in structural steel manufacturing company

Structural steel passes through various operations during the course of its fabrication. The fabrication operations that are valid for any structural steel manufacturer are shot blasting, cutting, drilling and punching, welding, testing and coating. Based on the manufacturer's extra capabilities there could be additional processes such as bending, tee splitting, pipe processing etc. Furthermore, the sequence and importance of fabrication operations vary depending on the type of the fabrication required. All these operations are stated in Table 3.2 and Figure 3.8. They are explained briefly in the subsequent parts of this section.

Table 3.2 : Operations in structural steel manufacturing process.

Operations	No
Surface Cleaning	1
Prefabrication Priming	2
Cutting	3
Drilling and Punching	4
Fitting and Reaming	5
Welding	6
Finishing	7
Quality Control	8
Surface Treatment	9

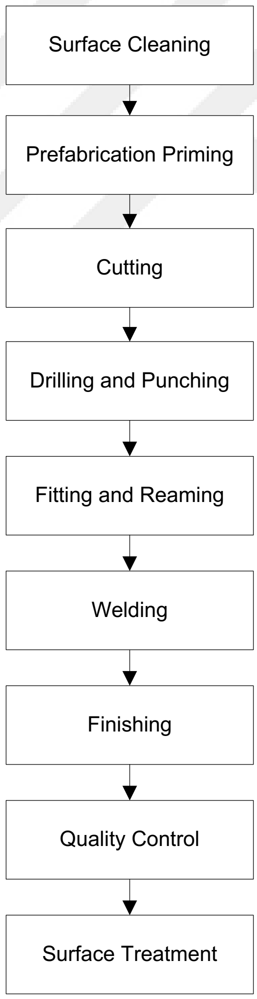

Figure 3.8 : Operations in structural steel manufacturing process.

3.6.3.1 Surface cleaning

Structural steel raw materials require surface cleaning to remove mill scale prior to fabrication. Hand cleaning (ex. wire brushing) does not generally conform to the requirements of modern coating systems. However, in some applications this manual method is used.

On the other hand, for many structural steel manufacturing companies as the case company under consideration, sections and plates are shot blasted prior to fabrication, although some choose to shot blast after the sections are cut to length.

This surface preparation is a crucial part of manufacturing process, which is essential to provide a suitably clean surface for welding and subsequently also to manufacture a keyed surface that is suitable for paint.

Shot is fired at the steel. The force of the shot against the surface displaces dirt and scale, moreover indents the steel creating a “rough” surface. When paint is sprayed onto this clean abraded surface it adheres well and accommodates a longevity for the paint system.

3.6.3.2 Prefabrication priming

After blast cleaning, prefabrication primers are applied in order to be sure that the reactive blast cleaned surface will be in a rust free condition through the manufacturing process until final painting.

3.6.3.3 Cutting

One of the first operations after prefabrication priming is to cut the sections to length and/or profile the plates to the desired size or shape. This activity is carried out by the suitable one of the following methods:

Circular saws

They are used for cutting to length of sections. The sections are positioned to the machine bed of the saw. Pre-programming system of the machine provides several advantages that are i) the section is accurately measured, ii) the section is cut to the length required, and iii) the operation is carried out at the most efficient speed for cutting operation to reduce wear on the blade.

Figure 3.9 : Circular saws.

Gas or flame cutting

They are used to cut components from steel plates. This machine use a mixture of oxygen and a fuel gas (propane) to preheat the metal to its ignition temperature that is still well below the steel's melting point. A jet of pure oxygen is then directed into the preheated area instigating a vigorous exothermic chemical reaction between the oxygen and the metal to form iron oxide or slag. The oxygen jet blows away the slag enabling the jet to pierce and continue to cut through the material.

Figure 3.10 : Flame cutting.

Plasma cutting

Plasma arc systems can also be used for cutting the components. A fine bore, copper nozzle constricts the arc between the electrode and the work piece. This increases the temperature and velocity of the plasma emanating from the nozzle.

3.6.3.4 Drilling and punching

All holes are pre-drilled or punched in the fabrication factory in order to make the steel structures be bolted together rapidly on the construction site. For drilling, high speed steel twist bits are used. The rotating bit cuts through the steel and the metal being removed during the process forms swarf (the curls of metal that spiral off during machining). The swarf travels up the flutes (the helical grooves), which run up the side of the bit.

Punching can be used where the thickness of the metal is less than the diameter of the hole or in the case of a non-circular hole its minimum dimension. In the punching process a cutting punch is forced under pressure through the steel into a die below, so producing a clean, accurately sized, hole.

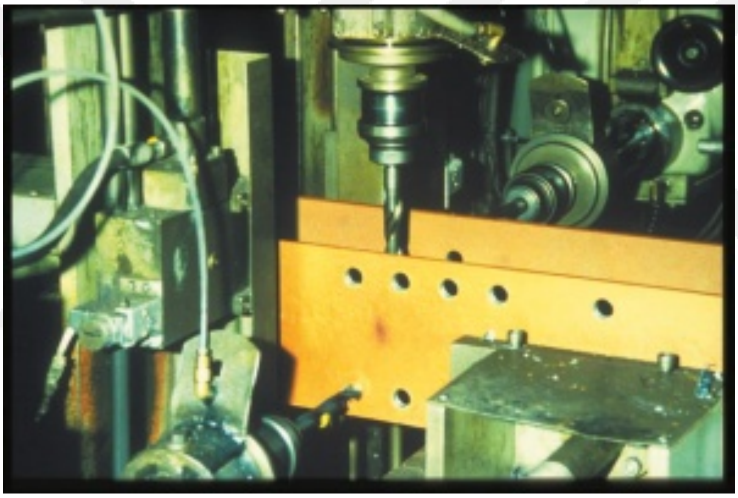

Figure 3.11 : Drilling process.

3.6.3.5 Fitting and reaming

Before final assembly, sub-products of a product are fitted up temporarily with rivets, bolts or small amount of welds. This operation consists the attachment of previously omitted splice plates and other fittings and the correction of minor defects found by the controller.

In riveted or bolted work, especially when done manually, some holes in the connecting sub-product may not always be in its perfect alignment and small amount of reaming may be required to let the insertion of fasteners. For this activity, the holes are punched, 4 to 6 mm smaller than final size, then after the sub-products are fixed together; the holes are reamed by electric or pneumatic reamers to the correct diameter, in order to manufacture well matched holes.

3.6.3.6 Welding

Welding is a core activity in the steel structure factory; it is used to prepare joints for connection on site and for the attachment of other fixtures and fittings. Different welding techniques are used for different activities within the fabrication factory.

Basically, the welding process uses an electric arc to generate heat to melt the parent material in the joint. A separate filler material supplied as a consumable electrode also melts and combines with the parent material to form a molten weld pool. The weld pool is susceptible to atmospheric contamination and therefore needs protecting during the critical liquid to solid freezing phase. Protection is achieved either by using an inert shielding gas, by covering the pool with an inert slag or a combination of both actions. As welding progresses along the joint, the weld pool solidifies fusing the parent and weld metal together. Several passes or runs may be required to fill the joint or to build up the weld to the design size.

Manual metal arc welding (MMA)

MMA or 'Shielded metal arc' welding is used to temporarily join or tack weld components during fabrication prior to full strength welding. Shielded metal arc welding employs a "Stick" type electrode covered with a flux coating. The electrode is brought into contact with the work piece and an electric arc between the electrode tip and the work piece is struck. The flux coating on the welding rod is heated to a gas and liquid. This shields the molten puddle from the atmosphere, hence its name - Shielded metal arc welding.

Figure 3.12 : Manual metal arc welding process.

Metal active gas welding (MAG)

Metal Active Gas (MAG) is used for continuous welding. MAG welding employs a continuous solid wire electrode carrying current. This is provided by a power source and fed through a "Gun" by a roller wire-feeder. An arc is struck between the continuous metal electrode and the steel work piece – this effectively melts the two together. The molten weld pool is protected from atmospheric oxidation by a gas shield.

Figure 3.13 : Metal active gas welding process.

Submerged arc welding (SAW)

For welding long pieces of steel together to fabricate structural sections, submerged arc welding is used. In Submerged arc welding a power current is applied to a continuous wire electrode. This is generally much larger diameter than in MAG welding. The arc is struck when the wire electrode contacts the work piece. Protection of the weld is provided by slag, formed by the action of the arc on a powder covering the whole weld reaction area. The arc is "Submerged" under the powder.

Non-destructive testing (NDT)

Non-destructive testing is used in order to be sure that welds are free from unacceptable defects such as cracks and inclusions. Magnetic particle inspection (MPI) and ultrasonic testing are the main NDT techniques. MPI utilizes a magnet and a magnetic liquid on the surface of the weld, and ultrasonic testing involves sending sound waves through the weld and interpreting the resulting echo pattern on an oscilloscope.

3.6.3.7 Finishing

Structural products whose ends must transmit loads by bearing against one another are usually finished to a smooth surface. This finishing is realized by sawing, milling or other suitable means.

3.6.3.8 Surface treatment

The application of paint coatings or hot dip galvanizing to the steelwork is carried out (if required) at the end of the fabrication process. Paint coating systems are generally applied in the fabrication factory to reduce site activity times and make significant cost savings. In addition to adding any aesthetic finish specified by architects, coatings are also widely used to provide corrosion protection, and fire resistance in the case of intumescent coatings.

Figure 3.14 : Surface treatment process.

Generally, the emphasis for buildings is on simple systems that are easy to apply involving spray application after automatic blasting. Many fabrication facilities have internal atmospheres that enable the steel to be blast cleaned before fabrication and surface coated afterwards. In such cases, the weld areas would require further surface preparation before coating, and components that are not too bulky can be re-blasted by passing them through the automatic blasting machine on a conveyor. Larger components would have to be manually blasted. To minimize this double handling, it makes economic sense to keep some components with no welding as these would not require re-blasting before coating application.

3.6.4 Assumptions

The below assumptions are considered in the mathematical model of the case study:

- There is no other project(s) in production in the initial point.
- There will be no weight losses or weight gain after each process.
- There is no cost for replacing the workstations to the new locations.
- There is no production loses while replacing the workstations.
- Outsourcing is not possible
- An expansion in capacities is not applicable.

3.6.5 Mathematical model of the case study

The mathematical model is summarized below in the closed formula form:

Parameters are:

B_x : the shop flow length (x-axis),

B_y : the shop flow width (y-axis),

L_i : the length of workstation i,

W_i : the width of workstation i,

k_i : the out-going flow of workstation i,

n_i : the capacity of workstation i,

c : the cost to move one unit per one distance unit from workstation i to workstation j,

M is a large number.

Decision variable are:

x_i: the x-coordinate of the left (west) side of workstation i ,

y_i : the y-coordinate of the bottom (south) side of workstation i ,

$f_{i,j}$: the flow frequency from workstation i to workstation j.

Binary variables are:

$zx_{i,j}$: is equal 1 if workstation i positions strictly to the east of workstation j,

Otherwise 0

$zy_{i,j}$: is equal 1 if workstation i positions strictly to the north of workstation j,

Otherwise 0.

Nonnegative variables:

$d_{i,j}^x$: are distances between workstation i and j in x axis,

$d_{i,j}^y$: are distances between workstation i and j in y axis.

Objective function:

$$min \sum_i \sum_j f_{i,j} \; c \left(d_{i,j}^x + d_{i,j}^y\right) \tag{3.8}$$

Subject to:

$$\sum_j f_{i,j} = k_i \qquad \text{for all } i \tag{3.9}$$

$$\sum_i f_{i,j} \leq n_j \qquad \text{for all } i \tag{3.10}$$

$$\sum_i f_{i,j} = \sum_i f_{j,i} \qquad \text{for all } j \tag{3.11}$$

$$0 \leq x_i \qquad \text{for all } i \tag{3.12}$$

$$x_i + L_i \leq \beta_x \qquad \text{for all } i \tag{3.13}$$

$$0 \leq y_i \qquad \text{for all } i \qquad (3.14)$$

$$y_i + W_i \leq \beta_y \qquad \text{for all } i \qquad (3.15)$$

$$d_{i,j}^x \geq (x_i + 0.5L_i) - (x_j + 0.5L_j) \qquad \text{for all } i \text{ and } j,\ i \neq j \qquad (3.16)$$

$$d_{i,j}^x \geq (x_j + 0.5L_j) - (x_i + 0.5L_i) \qquad \text{for all } i \text{ and } j,\ i \neq j \qquad (3.17)$$

$$d_{i,j}^y \geq (y_i + 0.5W_i) - (y_j + 0.5W_j) \qquad \text{for all } i \text{ and } j,\ i \neq j \qquad (3.18)$$

$$d_{i,j}^y \geq (y_j + 0.5W_j) - (y_i + 0.5W_i) \qquad \text{for all } i \text{ and } j,\ i \neq j \qquad (3.19)$$

$$x_j + L_j \leq x_i + M(1 - zx_{i,j}) \qquad \text{for all } i \text{ and } j,\ i \neq j \qquad (3.20)$$

$$y_j + W_j \leq y_i + M(1 - zy_{i,j}) \qquad \text{for all } i \text{ and } j,\ i \neq j \qquad (3.21)$$

$$zx_{i,j} + zx_{j,i} + zy_{i,j} + zy_{j,i} \geq 1 \qquad \text{for all } i \text{ and } j,\ i \neq j \qquad (3.22)$$

$$x_i, y_i \geq 0 \qquad \text{for all } i \qquad (3.23)$$

$$d_{i,j}^x, d_{i,j}^y \geq 0 \qquad \text{for all } i \text{ and } j,\ i \neq j \qquad (3.24)$$

$$zx_{i,j}, zy_{i,j} \quad \text{0/1 integer} \qquad \text{for all } i \text{ and } j,\ i \neq j \qquad (3.25)$$

The objective function given by equation 3.8 is the distance-based algorithm's objective. Constraint 3.9 defines the total outcome flow of workstation i. The capacity constraint for the total income flows of workstation i is given in constraint 3.10. Constraint 3.11 ensures that the income and outcome flows are equivalent for each workstation. Constraints 3.12, 3.13, 3.14, and 3.15 ensure that each workstation locates within facility floor's bound. Constraint 3.16, 3.17, 3.18 and 3.19 are required for linearization to avoid absolute value operator in objective function 3.8. Constraints 3.20, 3.21, and 3.22 ensure that each workstation is non-overlap by forcing a separation at least in the east-west or north-south direction. Equation 3.23 and 3.24 ensure the non-negative constraints. Finally, constraint 3.25 designates binary variables.

3.6.6 Chosen solver for mathematical model of the case study

The mathematical model is a nonlinear MIP model with continuous, binary and integer variables. As it is stated in Section 3.5, there are several solvers, which can solve this mathematical model. Couenne (Convex Over and Under ENvelopes for Nonlinear Estimation), which is an open source branch & bound algorithm for solving mixed integer nonlinear programming (MINLP) problems and finds globally optimal solutions to nonlinear problems regardless of convexity, is chosen to solve the problem. Couenne aims at finding global optima of MINLPs. It implements linearization, bound reduction, and branching methods within a Branch&Bound framework.

3.6.7 Equipment list and required area for operations

The equipment list of the company under consideration is given in Table 3.3.

Because there is an extra area requirement for the material and overhead crane movements and working area for workers, the required areas for the machines stated in Table 3.4. These required areas of the machines, the lengths of workstations and the widths of workstations are defined based on the experience of Factory Manager of the company under considerations.

Table 3.3 : Equipment list of the company under consideration.

Operations	Machines	Dimensions of Machines	Area of Machines	No
Surface Cleaning	1500-500 Shot Blasting Equipment	3m x 13m	39 m^2	1
Prefabrication Priming	Airless-spray unit (30:1)	2m x 6m	12 m^2	2
	Airless-spray unit (30:1)	2m x 6m	12 m^2	3
Cutting	Oxy-fuel CNC Cutting Unit	3m x 6m	18 m^2	4
	Oxy-fuel CNC Cutting Unit	2m x 6m	12 m^2	5
	Plasma CNC Cutting Unit	1,5m x13m	19.5 m^2	6
	Plasma CNC Cutting Unit	2m x 6m	12 m^2	7
	High Definition Plasma CNC Cutting	2m x 6m	12 m^2	8
	Hydraulic Variable Rake Shear	12m x 4m	48 m^2	9
	Automated Horizontal Mitre Cutting Bandsaw Line	1m x 0,6m	0.6 m^2	10
	Semi-Automatic Horizontal Cutting Bandsaw	0,28 x 0, 280	0.08 m^2	11
Drilling and Punching	CNC Gantry Type Drilling Unit (Q10 to Q34)	1m x 6m	6 m^2	12
	CNC Gantry Type Drilling Unit (Q10 to Q46)	1m x 6m	6 m^2	13
	Radial drilling Equipment (Q14 to Q54)	1m x 3m	3 m^2	14
	Radial drilling Equipment (Q14 to Q54)	1m x 3m	3 m^2	15
Fitting and Reaming	105 MIG Welding Machines			16
Welding	Jig Set Table for Assembly and Tack Welding	3mx35m	105 m^2	17
	Jig Set Table for Assembly and Tack Welding	3mx35m	105 m^2	18
	Jig Set Table for Assembly and Tack Welding	3mx35m	105 m^2	19
	Hydraulic Actuated, Automatic Assembly Jig Set and Fillet Welding Line	3mx60m	180 m^2	20
	Flage Splice Submerged Arc Full-penetration Welding Line	3mx25m	75 m^2	21
Finishing				22
Surface Treatment	Painting Spray Hand tools	4 m x 16 m	64 m^2	23

Table 3.4 : Required areas and limits of workstations.

No	Required Area (A_i)	L_i (m)	W_i (m)
1	42 m^2	14 m	3 m
2	21 m^2	7 m	3 m
3	21 m^2	7 m	3 m
4	45 m^2	9 m	5 m
5	36 m^2	9 m	4 m
6	68 m^2	17 m	4 m
7	21 m^2	7 m	3 m
8	21 m^2	7 m	3 m
9	105 m^2	7 m	15 m
10	8 m^2	4 m	2 m
11	4 m^2	2 m	2 m
12	24 m^2	8 m	3 m
13	24 m^2	8 m	3 m
14	15 m^2	5 m	3 m
15	15 m^2	5 m	3 m
16	60 m^2	15 m	4 m
17	228 m^2	38 m	6 m
18	228 m^2	38 m	6 m
19	228 m^2	38 m	6 m
20	420 m^2	70 m	6 m
21	145 m^2	29 m	5 m
22	125 m^2	25 m	5 m
23	162 m^2	27 m	6 m

3.6.8 Flow frequencies

The flows between workstations are given in Figure 3.15.

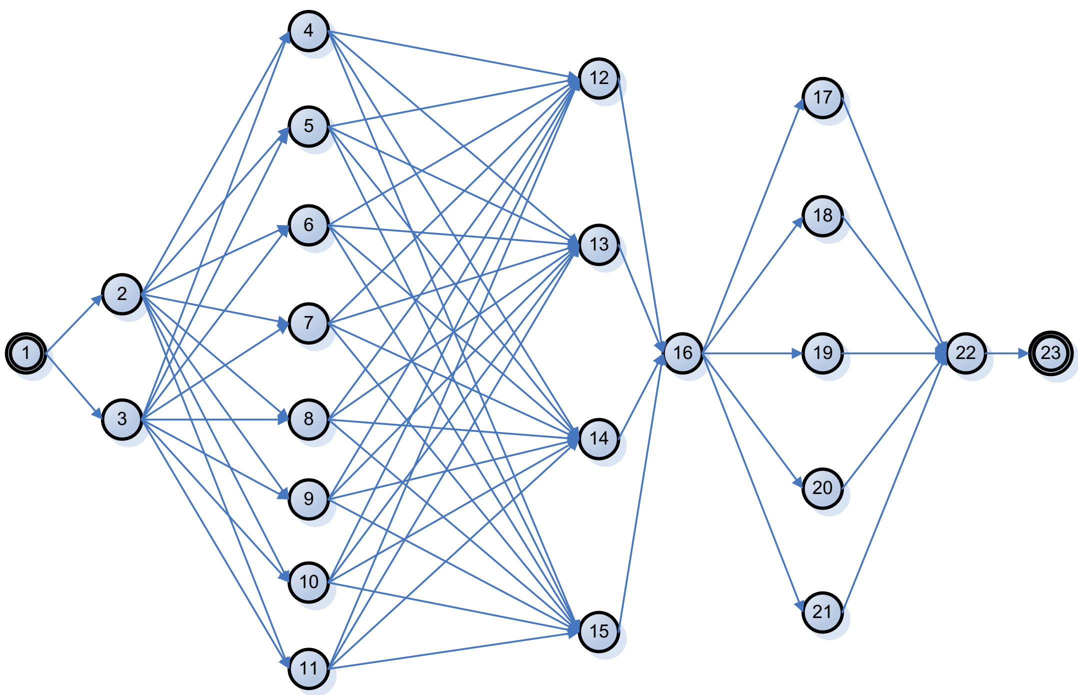

Figure 3.15 : The flows between workstations.

The flow frequencies from workstation i to workstation j are given in Table 3.5. The constraints based on Table 3.5 are stated in Appendix D.

Table 3.5 : Flow frequencies in tons from workstation i to workstation j.

No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0	5500		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 and 3	0	0	0	1050		2820		520	405	310	395	0	0	0	0	0	0	0	0	0	0	0	0
4 and 5	0	0	0	0	0	0	0	0	0	0	0	925		125		0	0	0	0	0	0	0	0
6 and 7	0	0	0	0	0	0	0	0	0	0	0	1570		1250		0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	470		50		0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	380		25		0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	240		70		0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	285		110		0	0	0	0	0	0	0	0
12 and 13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3870	0	0	0	0	0	0	0
14 and 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1630	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		3450		850	1200	0	0
17, 18 and 19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3450	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	850	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1200	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5500

3.6.9 Cost of moving one part

The cost of moving one part from one workstation to another is equal and it is USD1.5-/ton.

3.6.10 Cost of the problem with current layout

The current layout of the workstations in the factory under consideration is given in Figure 3.16.

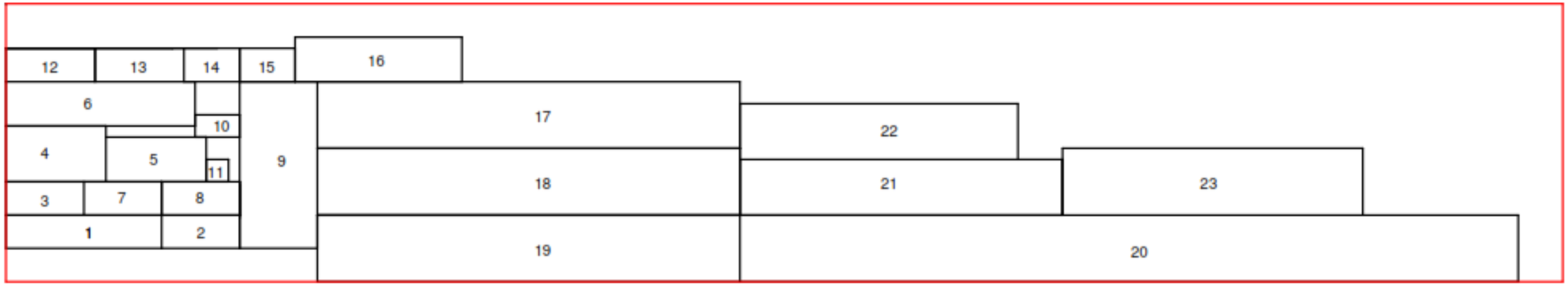

Figure 3.16 : The current layout of workstations in the factory.

The flows defined by the experience of the factory manager are given in Table 3.6.

Table 3.6 : Flows ($f_{i,j}$) defined by the experience of the factor manager.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	23	23
1	0	2500	3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	100	200	300	700	500	300	300	100	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	250	500	700	1120	20	105	10	295	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	200	50	50	50	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	200	475	10	15	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	150	600	200	50	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	500	320	300	700	0	0	0	0	0	0	0	0
8	s	0	0	0	0	0	0	0	0	0	0	270	200	25	25	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	300	80	10	15	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	120	120	35	35	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	185	100	60	50	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1925	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1945	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	690	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	940	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	1500	950	850	1200	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	950	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	850	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1200	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5500
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Based on the current location of the workstations the L_i, W_i, x_i and y_i values are stated in Table 3.7.

Table 3.7 : L_i, W_i, x_i and y_i values for current location.

	L_i	W_i	x_i	y_i
1	14	3	0	3
2	7	3	14	3
3	7	3	0	6
4	9	5	0	9
5	9	4	9	9
6	17	4	0	14
7	7	3	7	6
8	7	3	14	6
9	7	15	21	3
10	4	2	17	13
11	2	2	18	9
12	8	3	0	18
13	8	3	8	18
14	5	3	16	18
15	5	3	21	18
16	15	4	26	18
17	38	6	28	12
18	38	6	28	6
19	38	6	28	0
20	70	6	66	0
21	29	5	66	6
22	25	5	66	11
23	27	6	95	6

Distance of the workstations in x axis (d_x) for the current location of the workstations is given in Table 3.8.

Table 3.8 : Distance of the workstations in x axis (d_x).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	23	23
1	0	10.5	3.5	2.5	6.5	1.5	3.5	10.5	17.5	12	12	3	5	11.5	16.5	26.5	40	40	40	94	73.5	71.5	101.5
2	10.5	0	14	13	4	9	7	0	7	1.5	1.5	13.5	5.5	1	6	16	29.5	29.5	29.5	83.5	63	61	91
3	3.5	14	0	1	10	5	7	14	21	15.5	15.5	0.5	8.5	15	20	30	43.5	43.5	43.5	97.5	77	75	105
4	2.5	13	1	0	9	4	6	13	20	14.5	14.5	0.5	7.5	14	19	29	42.5	42.5	42.5	96.5	76	74	104
5	6.5	4	10	9	0	5	3	4	11	5.5	5.5	9.5	1.5	5	10	20	33.5	33.5	33.5	87.5	67	65	95
6	1.5	9	5	4	5	0	2	9	16	10.5	10.5	4.5	3.5	10	15	25	38.5	38.5	38.5	92.5	72	70	100
7	3.5	7	7	6	3	2	0	7	14	8.5	8.5	6.5	1.5	8	13	23	36.5	36.5	36.5	90.5	70	68	98
8	10.5	0	14	13	4	9	7	0	7	1.5	1.5	13.5	5.5	1	6	16	29.5	29.5	29.5	83.5	63	61	91
9	17.5	7	21	20	11	16	14	7	0	5.5	5.5	20.5	12.5	6	1	9	22.5	22.5	22.5	76.5	56	54	84
10	12	1.5	15.5	14.5	5.5	10.5	8.5	1.5	5,5	0	0	15	7	0.5	4.5	14.5	28	28	28	82	61.5	59.5	89.5
11	12	1.5	15.5	14.5	5.5	10.5	8.5	1.5	5,5	0	0	15	7	0.5	4.5	14.5	28	28	28	82	61.5	59.5	89.5
12	3	13.5	0,5	0.5	9.5	4.5	6.5	13.5	20,5	15	15	0	8	14.5	19.5	29.5	43	43	43	97	76.5	74.5	104.5
13	5	5.5	8.5	7.5	1.5	3.5	1.5	5.5	12,5	7	7	8	0	6.5	11.5	21.5	35	35	35	89	68.5	66.5	96.5
14	11.5	1	15	14	5	10	8	1	6	0.5	0.5	14.5	6.5	0	5	15	28.5	28.5	28.5	82.5	62	60	90
15	16.5	6	20	19	10	15	13	6	1	4.5	4.5	19.5	11.5	5	0	10	23.5	23.5	23.5	77.5	57	55	85
16	26.5	16	30	29	20	25	23	16	9	14.5	14.5	29.5	21.5	15	10	0	13.5	13.5	13.5	67.5	47	45	75
17	40	29.5	43.5	42.5	33.5	38.5	36.5	29.5	22.5	28	28	43	35	28.5	23.5	13.5	0	0	0	54	33.5	31.5	61.5
18	40	29.5	43.5	42.5	33.5	38.5	36.5	29.5	22.5	28	28	43	35	28.5	23.5	13.5	0	0	0	54	33.5	31.5	61.5
19	40	29.5	43.5	42.5	33.5	38.5	36.5	29.5	22.5	28	28	43	35	28.5	23.5	13.5	0	0	0	54	33.5	31.5	61.5
20	94	83.5	97.5	96.5	87.5	92.5	90.5	83.5	76.5	82	82	97	89	82.5	77.5	67.5	54	54	54	0	20.5	22.5	7.5
21	73.5	63	77	76	67	72	70	63	56	61.5	61.5	76.5	68.5	62	57	47	33.5	33.5	33.5	20.5	0	2	28
22	71.5	61	75	74	65	70	68	61	54	59.5	59.5	74.5	66,5	60	55	45	31.5	31.5	31.5	22.5	2	0	30
23	101.5	91	105	104	95	100	98	91	84	89.5	89.5	104.5	96.5	90	85	75	61.5	61.5	61.5	7.5	28	30	0

Distance of the workstations in y axis (d_y) for the current location of the workstations is given in Table 3.9.

Table 3.9 : Distance of the workstations in y axis (d_y).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	23	23
1	0	0	3	7	6.5	11.5	3	3	6	9.5	5.5	15	15	15	15	15.5	10.5	4.5	1.5	1.5	4	9	4.5
2	0	0	3	7	6.5	11.5	3	3	6	9.5	5.5	15	15	15	15	15.5	10.5	4.5	1.5	1.5	4	9	4.5
3	3	3	0	4	3.5	8.5	0	0	3	6.5	2.5	12	12	12	12	12.5	7.5	1.5	4.5	4.5	1	6	1.5
4	7	7	4	0	0.5	4.5	4	4	1	2.5	1.5	8	8	8	8	8.5	3.5	2.5	8.5	8.5	3	2	2.5
5	6.5	6.5	3.5	0.5	0	5	3.5	3.5	0.5	3	1	8.5	8.5	8.5	8.5	9	4	2	8	8	2.5	2.5	2
6	11.5	11.5	8.5	4.5	5	0	8.5	8.5	5.5	2	6	3.5	3.5	3.5	3.5	4	1	7	13	13	7.5	2.5	7
7	3	3	0	4	3.5	8.5	0	0	3	6.5	2.5	12	12	12	12	12.5	7.5	1.5	4.5	4.5	1	6	1.5
8	3	3	0	4	3.5	8.5	0	0	3	6.5	2.5	12	12	12	12	12.5	7.5	1.5	4.5	4.5	1	6	1.5
9	6	6	3	1	0.5	5.5	3	3	0	3.5	0.5	9	9	9	9	9.5	4.5	1.5	7.5	7.5	2	3	1.5
10	9.5	9.5	6.5	2.5	3	2	6.5	6.5	3.5	0	4	5.5	5.5	5.5	5.5	6	1	5	11	11	5.5	0.5	5
11	5.5	5.5	2.5	1.5	1	6	2.5	2.5	0.5	4	0	9.5	9.5	9.5	9.5	10	5	1	7	7	1.5	3.5	1
12	15	15	12	8	8.5	3.5	12	12	9	5.5	9.5	0	0	0	0	0.5	4.5	10.5	16.5	16.5	11	6	10.5
13	15	15	12	8	8.5	3.5	12	12	9	5.5	9.5	0	0	0	0	0.5	4.5	10.5	16.5	16.5	11	6	10.5
14	15	15	12	8	8.5	3.5	12	12	9	5.5	9.5	0	0	0	0	0.5	4.5	10.5	16.5	16.5	11	6	10.5
15	15	15	12	8	8.5	3.5	12	12	9	5.5	9.5	0	0	0	0	0.5	4.5	10.5	16.5	16.5	11	6	10.5
16	15.5	15.5	12.5	8.5	9	4	12.5	12.5	9.5	6	10	0.5	0.5	0.5	0.5	0	5	11	17	17	11.5	6.5	11
17	10.5	10.5	7.5	3.5	4	1	7.5	7.5	4.5	1	5	4.5	4.5	4.5	4.5	5	0	6	12	12	6.5	1.5	6
18	4.5	4.5	1.5	2.5	2	7	1.5	1.5	1.5	5	1	10.5	10.5	10.5	10.5	11	6	0	6	6	0.5	4.5	0
19	1.5	1.5	4.5	8.5	8	13	4.5	4.5	7.5	11	7	16.5	16.5	16.5	16.5	17	12	6	0	0	5.5	10.5	6
20	1.5	1.5	4.5	8.5	8	13	4.5	4.5	7.5	11	7	16.5	16.5	16.5	16.5	17	12	6	0	0	5.5	10.5	6
21	4	4	1	3	2.5	7.5	1	1	2	5.5	1.5	11	11	11	11	11.5	6.5	0.5	5.5	5.5	0	5	0.5
22	9	9	6	2	2.5	2.5	6	6	3	0.5	3.5	6	6	6	6	6.5	1.5	4.5	10.5	10.5	5	0	4.5
23	4.5	4.5	1.5	2.5	2	7	1.5	1.5	1.5	5	1	10.5	10.5	10.5	10.5	11	6	0	6	6	0.5	4.5	0

The total cost for the current location of the workstations is given in Table 3.10.

Table 3.10 : The total cost for the current location of the factory.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	23	23
1	0	39,375	29,250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	3,000	3,150	9,225	10,500	2,250	5,850	4,950	1,050	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	1,875	10,125	14,175	11,760	420	3,780	330	7,965	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	2,550	1,163	1,650	2,025	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	5,400	7,125	203	416	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	1,800	6,300	4,050	1,388	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	13,875	6,480	9,000	26,250	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	10,328	5,250	488	675	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	13,275	2,580	225	225	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	3,690	2,250	315	525	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	6,799	2,475	900	1,050	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86,625	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64,185	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16,043	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14,805	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27,750	55,125	43,463	107,738	105,300	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49,500	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	81,000	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	59,850	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42,075	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12,600	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	284,625
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
												TOTAL = USD1,350,435											

3.6.11 Cost of the problem with mathematical model

The mathematical model formulated in AMPL is solved with Couenne solver. Couenne is an open source code for solving Global Optimization problems; i.e., problems of the form (P) (URL4):

$$\min f(x) \tag{3.26}$$

$$s.t. g_j(x) \leq 0 \qquad \forall j \in M \tag{3.27}$$

$$x_i^l \leq x_i \leq x_i^u \qquad \forall i \in N_0 \tag{3.28}$$

$$x_i \in \mathbb{Z} \qquad \forall i \in N_0^I \subseteq N_0 \tag{3.29}$$

Where $f: R^n \rightarrow \mathbb{R}$ and, for all $j \in M$, $g_j: R^n \rightarrow \mathbb{R}$ are multivariate (possibly nonconvex) functions, $n = |\mathrm{N}_o|$ is the number of variables, and $x = (x_i)_{i \in N_o}$ is the n-vector of variables. It is assumed that f and g_j's are factorable, i.e., they are defined as $\sum_h \prod_k \mathfrak{y}_{hk}(x)$, where all functions $\mathfrak{y}_{hk}(x)$ are univariate.

Couenne is a reformulation based spatial branch & bound and it implements:

- linearization;
- branching;
- heuristics to find feasible solutions;
- bound reduction.

The initial problem is reformulated by introducing a new set of variables, called auxiliary variables. After reformulation, the problem looks like as below (P'):

$$\min w_{n+q} \tag{3.30}$$

$$s.t. \qquad w_i = \vartheta_i(x, w_{n+1}, w_{n+2} \dots, w_{i-1} \qquad i \in Q \tag{3.31}$$

$$w_i^l \leq w_i \leq w_i^u \qquad i \in Q \tag{3.32}$$

$$x_i^l \leq x_i \leq x_i^u \qquad i \in N_o \tag{3.33}$$

$$x_i \in \mathbb{Z} \qquad i \in N_o^I \subseteq N_o \tag{3.34}$$

$$w_i \in \mathbb{Z} \qquad i \in Q_I \subseteq \mathrm{Q} \tag{3.35}$$

The problem is not easier to solve by reformulation, as it simply creates a brunch of new variables. It is easier to gather a lower bound on the optimal solution of (P') than it is for (P).

After reformulation, a linearization step allows to obtain a Linear Programing relaxation of (P') and hence of (P), that can be easily embedded in a branch-and bound framework. Couenne adds the below components:

- bound tightening technique-s: They are used to infer better bounds on all variables (both original and auxiliary), in order to achieve a tighter lower bound;
- heuristics to obtain a feasible solution;
- branching techniques for partitioning the set of solutions.

Lastusilta (2011) studied the solving capability of some solvers for optimization problems in his PhD thesis. He aimed to reveal if there exists a commercial MINLP solver that is universally faster and finds a higher quality solution than any of the other solvers. He intended to uncover the difficulties of performing a fair comparison. This research was carried out by performing solver comparisons with very extensive MinlpLib problem library which had 270 models.

Based on the study of Lastusilta (2011), Figure 3.17 presents the ability of compared solvers to find solutions when different time limits are considered. Although Bonmin finds a solution for more problems within 10 seconds (nearly 65% of the problems) rather than other solvers, it finds best solution with 37% which is close to Couenne's performance which is 34%. When the spent time is longer Couenne and Bonmin has nearly the same performance in find a solution and best solution. Baron has the worst performance in any condition.

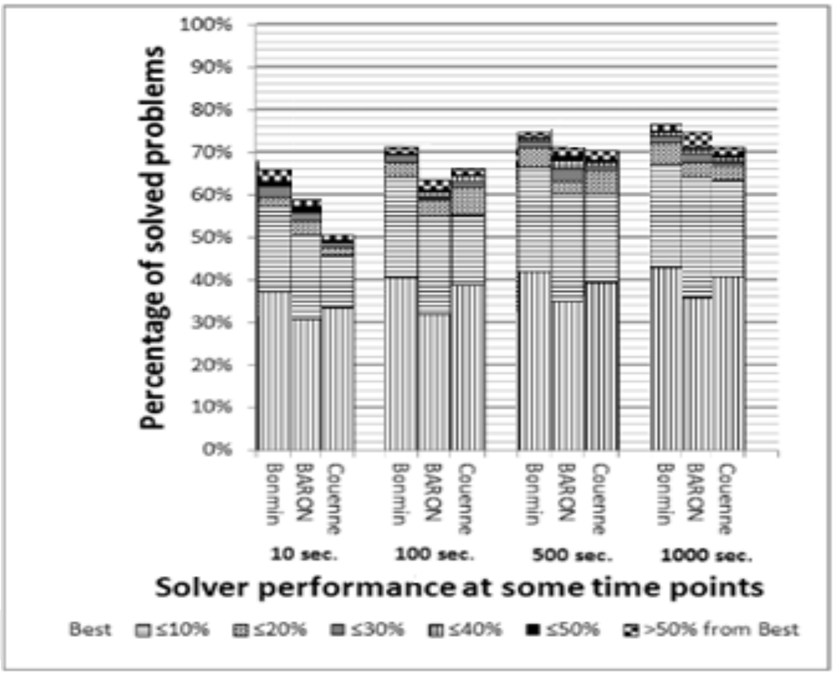

Figure 3.17 : MinlpLib: a solution quality comparison for MINLP solvers.

Based on the solution of the mathematical model formulated in AMPL, and solved with Couenne which took 63 hours to find the solution, the layout of the workstations in the factory under consideration is assessed as stated in Figure 3.18.

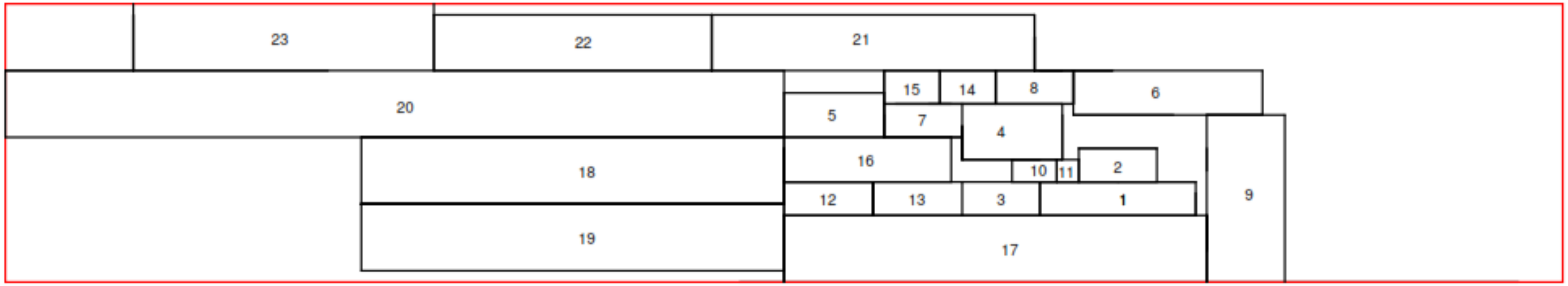

Figure 3.18 : The layout of workstations in the factory based on mathematical model solution.

The flows computed by the mathematical model are given in Table 3.11.

Table 3.11 : Flows ($f_{i,j}$) computed by the mathematical model.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	23	23
1	0	2987	2513	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	137	545	771	512	360	405	21	236	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	163	205	0	1537	160	0	289	159	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	47	128	64	61	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	731	19	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	193	222	170	186	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	46	1109	325	569	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	24	446	50	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	380	0	8	17	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	37	203	70	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	12	273	58	52	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1470	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2400	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	745	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	885	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	335	1516	1599	850	1200	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1600	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1600	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	850	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1200	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5500
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Given parameters (L_i , W_i) and computed variables (x_i and y_i) for the mathematical model are stated in Table 3.12.

Table 3.12 : Given parameters (L_i , W_i) and computed variables (x_i and y_i) for the mathematical model.

	L_i	W_i	x_i	y_i
1	14	3	93	6
2	7	3	96.5	9
3	7	3	86	6
4	9	5	86	11
5	9	4	70	13
6	17	4	96	15
7	7	3	79	13
8	7	3	89	16
9	7	15	108	0
10	4	2	90.5	9
11	2	2	94.5	9
12	8	3	70	6
13	8	3	78	6
14	5	3	84	16
15	5	3	79	16
16	15	4	70	9
17	38	6	70	0
18	38	6	32	7
19	38	6	32	1
20	70	6	0	13
21	29	5	63.5	19
22	25	5	38.5	19
23	27	6	11.5	19

Distance of the workstations in x axis (d_x) for the mathematical model location of the workstations is given in Table 3.13.

Table 3.13 : Distance of the workstations in x axis (d_x).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	23	23
1	0	0	10.5	9.5	25.5	4.5	17.5	7.5	11.5	7.5	4.5	26	18	13.5	18.5	22.5	11	49	49	65	22	49	75
2	0	0	10.5	9.5	25.5	4.5	17.5	7.5	11.5	7.5	4.5	26	18	13.5	18.5	22.5	11	49	49	65	22	49	75
3	10.5	10.5	0	1	15	15	7	3	22	3	6	15.5	7.5	3	8	12	0.5	38.5	38.5	54.5	11.5	38.5	64.5
4	9.5	9.5	1	0	16	14	8	2	21	2	5	16.5	8.5	4	9	13	1.5	39.5	39.5	55.5	12.5	39.5	65.5
5	25.5	25.5	15	16	0	30	8	18	37	18	21	0.5	7.5	12	7	3	14.5	23.5	23.5	39.5	3.5	23.5	49.5
6	4.5	4.5	15	14	30	0	22	12	7	12	9	30.5	22.5	18	23	27	15.5	53.5	53.5	69.5	26.5	53.5	79.5
7	17.5	17.5	7	8	8	22	0	10	29	10	13	8.5	0.5	4	1	5	6.5	31.5	31.5	47.5	4.5	31.5	57.5
8	7.5	7.5	3	2	18	12	10	0	19	0	3	18.5	10.5	6	11	15	3.5	41.5	41.5	57.5	14.5	41.5	67.5
9	11.5	11.5	22	21	37	7	29	19	0	19	16	37.5	29.5	25	30	34	22.5	60.5	60.5	76.5	33.5	60.5	86.5
10	7.5	7.5	3	2	18	12	10	0	19	0	3	18.5	10.5	6	11	15	3.5	41.5	41.5	57.5	14.5	41.5	67.5
11	4.5	4.5	6	5	21	9	13	3	16	3	0	21.5	13.5	9	14	18	6.5	44.5	44.5	60.5	17.5	44.5	70.5
12	26	26	15.5	16.5	0.5	30.5	8.5	18.5	37.5	18.5	21.5	0	8	12.5	7.5	3.5	15	23	23	39	4	23	49
13	18	18	7.5	8.5	7.5	22.5	0.5	10.5	29.5	10.5	13.5	8	0	4.5	0.5	4.5	7	31	31	47	4	31	57
14	13.5	13.5	3	4	12	18	4	6	25	6	9	12.5	4.5	0	5	9	2.5	35.5	35.5	51.5	8.5	35.5	61.5
15	18.5	18.5	8	9	7	23	1	11	30	11	14	7.5	0.5	5	0	4	7.5	30.5	30.5	46.5	3.5	30.5	56.5
16	22.5	22.5	12	13	3	27	5	15	34	15	18	3.5	4.5	9	4	0	11.5	26.5	26.5	42.5	0.5	26.5	52.5
17	11	11	0.5	1.5	14.5	15.5	6.5	3.5	22.5	3.5	6.5	15	7	2.5	7.5	11.5	0	38	38	54	11	38	64
18	49	49	38.5	39.5	23.5	53.5	31.5	41.5	60.5	41.5	44.5	23	31	35.5	30.5	26.5	38	0	0	16	27	0	26
19	49	49	38.5	39.5	23.5	53.5	31.5	41.5	60.5	41.5	44.5	23	31	35.5	30.5	26.5	38	0	0	16	27	0	26
20	65	65	54.5	55.5	39.5	69.5	47.5	57.5	76.5	57.5	60.5	39	47	51.5	46.5	42.5	54	16	16	0	43	16	10
21	22	22	11.5	12.5	3.5	26.5	4.5	14.5	33.5	14.5	17.5	4	4	8.5	3.5	0.5	11	27	27	43	0	27	53
22	49	49	38.5	39.5	23.5	53.5	31.5	41.5	60.5	41.5	44.5	23	31	35.5	30.5	26.5	38	0	0	16	27	0	26
23	75	75	64.5	65.5	49.5	79.5	57.5	67.5	86.5	67.5	70.5	49	57	61.5	56.5	52.5	64	26	26	10	53	26	0

Distance of the workstations in y axis (d_y) for the mathematical model location of the workstations is given in Table 3.14.

Table 3.14 : Distance of the workstations in y axis (d_y).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	23	23
1	0	3	0	6	7.5	9.5	7	10	0	2.5	2.5	0	0	10	10	3.5	4.5	2.5	3.5	8.5	14	14	14.5
2	3	0	3	3	4.5	6.5	4	7	3	0.5	0.5	3	3	7	7	0.5	7.5	0.5	6.5	5.5	11	11	11.5
3	0	3	0	6	7.5	9.5	7	10	0	2.5	2.5	0	0	10	10	3.5	4.5	2.5	3.5	8.5	14	14	14.5
4	6	3	6	0	1.5	3.5	1	4	6	3.5	3.5	6	6	4	4	2.5	10.5	3.5	9.5	2.5	8	8	8.5
5	7.5	4.5	7.5	1.5	0	2	0.5	2.5	7.5	5	5	7.5	7.5	2.5	2.5	4	12	5	11	1	6.5	6.5	7
6	9.5	6.5	9.5	3.5	2	0	2.5	0.5	9.5	7	7	9.5	9.5	0.5	0.5	6	14	7	13	1	4.5	4.5	5
7	7	4	7	1	0.5	2.5	0	3	7	4.5	4.5	7	7	3	3	3.5	11.5	4.5	10.5	1.5	7	7	7.5
8	10	7	10	4	2.5	0.5	3	0	10	7.5	7.5	10	10	0	0	6.5	14.5	7.5	13.5	1.5	4	4	4.5
9	0	3	0	6	7.5	9.5	7	10	0	2.5	2.5	0	0	10	10	3.5	4.5	2.5	3.5	8.5	14	14	14.5
10	2.5	0.5	2.5	3.5	5	7	4.5	7.5	2.5	0	0	2.5	2.5	7.5	7.5	1	7	0	6	6	11.5	11.5	12
11	2.5	0.5	2.5	3.5	5	7	4.5	7.5	2.5	0	0	2.5	2.5	7.5	7.5	1	7	0	6	6	11.5	11.5	12
12	0	3	0	6	7.5	9.5	7	10	0	2.5	2.5	0	0	10	10	3.5	4.5	2.5	3.5	8.5	14	14	14.5
13	0	3	0	6	7.5	9.5	7	10	0	2.5	2.5	0	0	10	10	3.5	4.5	2.5	3.5	8.5	14	14	14.5
14	10	7	10	4	2.5	0.5	3	0	10	7.5	7.5	10	10	0	0	6.5	14.5	7.5	13.5	1.5	4	4	4.5
15	10	7	10	4	2.5	0.5	3	0	10	7.5	7.5	10	10	0	0	6.5	14.5	7.5	13.5	1.5	4	4	4.5
16	3.5	0.5	3.5	2.5	4	6	3.5	6.5	3.5	1	1	3.5	3.5	6.5	6.5	0	8	1	7	5	10.5	10.5	11
17	4.5	7.5	4.5	10.5	12	14	11.5	14.5	4.5	7	7	4.5	4.5	14.5	14.5	8	0	7	1	13	18.5	18.5	19
18	2.5	0.5	2.5	3.5	5	7	4.5	7.5	2.5	0	0	2.5	2.5	7.5	7.5	1	7	0	6	6	11.5	11.5	12
19	3.5	6.5	3.5	9.5	11	13	10.5	13.5	3.5	6	6	3.5	3.5	13.5	13.5	7	1	6	0	12	17.5	17.5	18
20	8.5	5.5	8.5	2.5	1	1	1.5	1.5	8.5	6	6	8.5	8.5	1.5	1.5	5	13	6	12	0	5.5	5.5	6
21	14	11	14	8	6.5	4.5	7	4	14	11.5	11.5	14	14	4	4	10.5	18.5	11.5	17.5	5.5	0	0	0.5
22	14	11	14	8	6.5	4.5	7	4	14	11.5	11.5	14	14	4	4	10.5	18.5	11.5	17.5	5.5	0	0	0.5
23	14.5	11.5	14.5	8.5	7	5	7.5	4.5	14.5	12	12	14.5	14.5	4.5	4.5	11	19	12	18	6	0.5	0.5	0

The total cost for the mathematical model location of the workstations is given in Table 3.15.

Table 3.15 : The total cost for the mathematical model of the factory.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	23	23
1	0	13,442	39,580	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	2,569	24,525	12,722	16,512	7,830	8,809	252	1,770	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	1,712	6,919	0	32,277	3,120	0	2,384	2,027	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	1,586	2,784	768	1,190	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	8,772	428	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	11,580	10,656	4,718	6,557	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	1,070	12,476	3,413	3,414	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	1,026	13,715	450	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	21,375	0	420	1,020	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	1,166	3,959	1,418	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	432	6,552	1,436	1,677	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15,435	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28,800	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17,321	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13,939	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9,799	62,535	80,350	60,563	19,800	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	135,600	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27,600	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,563	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27,413	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48,600	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	218,625
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL = USD1,073,442																							

3.6.12 Cost comparison for current and mathematical model layouts

The comparison of cost with current layout design stated in Section 3.6.9, and cost of mathematical model layout design stated in Section 3.6.10 are presented in Table 3.16.

Table 3.16 : Cost comparison for current and mathematical model layout designs.

	Current layout design	Mathematical model layout design
Cost	USD1,350,435	USD1,073,442

According to Table 3.22, if the current factory layout was considered in the production, the total manufacturing cost would be USD1,350,435-. On the other hand, the total production cost of the proposed mathematical model is computed as USD1,072,442-, which is more than 20 percent less than the current location cost.

4. CONCLUSIONS AND RECOMMENDATIONS

In the condition where the demands of the customers exceed the manufacturer's capacities, the manufacturer should make a selection from the potential orders. Therefore, the potential orders should be prioritized. This prioritization research verbalizes the need for using an MCDM tool like ANP for solving real life problems of production industries, structural steel manufacturing company in this case. Customer order prioritization displays a highly relevant research topic, which has also a high managerial interest in structural steel manufacturing companies dealing with capacity limitations. An ANP framework was applied for the case study research. The criteria which were used in prioritization of the orders were potential profit rate per unit of time, the compatibility of potential order with the available capacity, the level of potential future order with higher profit, customer credit of future business opportunity, and the negotiability level of production schedule for the order. The evaluated alternatives were administrative building in Gemlik, shopping center in Sapanca, housing project in Algeria, factory in Pakistan, water sports center in Cengelkoy, city hall project in Georgia.

As per findings of prioritization decision framework, with respect to "potential profit rate" and "customer credit of future business opportunity", the most favored project was "Administrative Building in Gemlik" with a relative priorities of 27.16% and 32.19%, respectively. Moreover, "Shopping center in Sapanca" was the most preferred project with priorities of 42.19% and 38.2% when "the level of potential future order with higher profit" and "the negotiability level of production schedule for the order" were taken into consideration. Finally, with respect to "available capacity", the most preferred project was "Factory in Pakistan" (25.48%).

"Customer credit of future business opportunity" criterion had the highest impact on "Water sports center in Cengelkoy" (35.07%), "Shopping center in Sapanca" (41.23%), "Administrative building in Gemlik" (51.84%), and "Housing project in Algeria" (45.59%). Furthermore, "potential profit rate" had the highest impact on "factory in Pakistan" (48.84%) and "City hall project in Georgia" (52.05%). Finally, “the level of potential future order with higher profit” had the highest impact on “Compressor station in Eskisehir” (37.16%).

To combine individual priorities of the alternatives and criteria together and reveal global priorities of them, the software converted supermatrix to limit matrix by raising it to large powers where converged or stable values exist. As previously mentioned, the output of the limit matrix can be converted to the descending priority orders which represent the global preferences for potential projects and the relative importance of evaluation criteria as can be seen at Table 2.4 and 2.5.

Based on the priorities of the criteria, “customer credit of future business opportunity” was found as the most important one (35.48%), followed by “potential profit rate per unit of time” (26.77%). Other evaluation criteria, namely “the negotiability level of production schedule for the order”, “the level of potential future order with higher profit”, “and “the compatibility of potential order with the available capacity” were found less important than the first two criteria. Their relative priorities were 14.38%, 12.11%, and 11.26%, respectively.

The most preferred potential project was “Administrative building in Gemlik” (21.64%), followed by “Shopping center in Sapanca” (20.82%). The subsequent projects were “Housing project in Algeria” (15.68%), “Factory in Pakistan” (12.68%), and “Water sports center in Cengelkoy” (11.01%), and “City hall project in Georgia” (10.37%). The least preferred project was “Compressor station in Eskisehir” (7.81%). The firm under the limited capacities was suggested to choose alternatives respectively in accordance with the prioritization, considering the assessment criteria of customer credit of future business opportunity, the potential profit rate per unit of time, the negotiability level of production schedule for the order, the level of potential future order with higher profit, and the compatibility of potential order with the available capacity.

At the point when the prioritization order of alternatives proposed by the framework was shared with the top-management of the firm, it has been found out that the managers’ expectations were different from this result. Despite the fact that the ranking orders of the managers were different from each other, the regular desire of them was same for the first order: Factory in Pakistan. Regarding to the results, Pakistan project had the 4th position among 7 alternatives. Though unexpected initially, this result was not surprising to DAs. After the following clarifications, the managers agreed, as well. Cognitive psychology brings up that as people are poor at assimilating huge amount of data on problems and furthermore cope with cognitive overload by employing heuristics that easify the problem, suboptimal alternatives can be chosen (Miller, 1956). The desires of the managers about Factory in Pakistan support perspective of Miller. Moreover, if there are interdependencies among the factors, the factors that are less important individually might turn out to be more important when evaluated collectively (Karpak and Topcu, 2010). The human mind can only capture first (maybe second) degree of influences. A systematic approach such as ANP to capture second, third and higher degree of influences is required.

The purpose of any multi criteria decision aid technique is to give assistance and guidance to the decision makers in discovering their most desired solution to the problem. The recommendation is made based on the result of a knapsack problem in which the priorities of the criteria were supposed to be the coefficients of the objective function and the company's design and production capacity is considered as a constraint. After sharing the results, the firm is monitored to ensure that the recommendation is enabling managers of the firm to meet their aims. It is realized that in accordance with the recommendation, the first, the second, and the fourth customer orders; namely Administrative Building in Gemlik, Shopping Center in Sapanca, Factory in Pakistan; are suitable for the DMs to choose.

After the project selection, facility layout design especially for these projects is required by the company in order to maximize the effectiveness of the production process and minimizing production cost. Therefore, a decision framework for facility layout design is developed in this study.

Because the awarded projects are usually long-term projects and cover a very large portion or sometimes all of the manufacturer's capacities and projects are always unique in terms of production, the facility layout should be redesigned by new orders. The factory characteristics namely "product variety and volume", "facility shapes and dimensions", "material handling system", "number of floors in the facility", "backtracking and by passing", and "pick-up and drop-off locations" were considered in the design of the facility layout.

The facility layout design verbalizes the need for developing a mathematical model formulation for solving a real life problem of production industries, structural steel manufacturing company in this case. For this aim, A MINLP mathematical model with continuous, binary and integer variables was developed to design the facility. Facility layout design is a crucial topic, which has also a high managerial interest in structural steel manufacturing companies dealing with production efficiency and cost. AMPL software was used in formulation of the mathematical model and solver Couenne is utilized for finding the solution.

First of all, the current factory layout is considered for the total cost calculation in order to compare the MINLP mathematical model efficiency. In the current factory layout design calculation, the factory manager is requested to define the flows between workstations based on his experience. The total cost for the current layout was computed as USD1,350,435-.

In MINLP mathematical model solution, although the flows in between group of machines are defined, the flow between each workstation was defined by optimization. As per findings of the mathematical model solution, the total cost was USD1,072,442 which is more than 20% cheaper than the current solution. Therefore, it can be declared that the MINLP mathematical model gives an effective and cost saving solution.

4.1 Practical Application of the Study

4.1.1 Managerial implication

Based on the literature review, this is the first study in prioritizing customer orders in a multi-criteria decision-making environment and designing the facility layout sequentially for the production firms in steel industry. Besides, evaluation criteria are settled and prioritized as well. Moreover, the total cost with current factory design is also calculated to compare with the MINLP mathematical model solution. The proposed decision aid approaches are used at a structural steel manufacturing company as a case study. Although it is not possible to generalize the findings for the steel structure industry, it would be an insight for the managers that require to prioritize client orders and to design the facility for chosen orders. For this aim, the iterative steps of the decision making process and the facility layout design process presented in this study can be used for other make-to-order companies' potential and selected orders. Moreover, the firms in the same industry with the firm under consideration can also be analyzed and their priorities and facility layout cost savings can also be gathered. The comparison of these models' results can present an idea about the differentiation in criteria of the firm in the way of prioritizing the alternatives and improvement in cost savings in the way of designing the facility layout.

Strengths of the research are:

- the availability of accumulating the survey and getting flow frequencies from/to each machine group from the top-management level of the firm.
- the validation of model's criteria and factory characteristics by the literature and as well as the top-managers' experiences.
- the availability of the real potential alternative projects of the firm.
- the availability to design the facility for the chosen real projects.

4.1.2 Theoretical implication

It is expected that this study might inspire some researchers to use ANP methodology in manufacturing decision problems when there are dependencies and feedback among the related factors. Both quantitative and qualitative criteria are used by ANP. The relative strength of direct influences of two factors with respect to the third (controlling) factor are requested; other degrees of influences are captured by ANP.

This study can be an insight for the researches to use MINLP mathematical models in facility layout design for real cases in production industry. Both factory characteristics and layout types are considered in the MINLP mathematical model. AMPL software and Couenne solver are used in the solution of the MINLP mathematical model.

4.2 Limitations and Direction for Future Research

The limitations and direction for future research are stated below:

- Only the top-management (business development, factory and technical office managers) who were in charge of making strategic decisions were the respondents of the survey and facility layout design decisions. As a further research avenue, the respondents can be extended to a broader group of decision makers, if required.

- The ANP model is also suitable for creating the set of criteria (creating sub-criteria for some criteria). If different clusters can be built up, the effects of these clusters can be assessed also.
- The MINLP facility layout model was actualized by making the assumptions stated in section 3.6.4. These assumptions can be considered in the MINLP mathematical model to receive a solution which can improve the strength of the study.
- The MINLP mathematical model of the study can solve the facility layout problems to minimize material handling cost and design the layout of workstations without any loss of any workstation's required area within the boundary of the facility floor's dimensions. Suggested future works are:
    - to vary facility's area by using heuristic algorithm to reduce the total area requirement, evaluating the relationship between facility floor's area and material handling cost.
    - to consider flexible widths and lengths for the workstations and constant area requirements.
    - to consider constant "equipment areas" and flexible "pick-up, drop-off, and working areas".
- In this case, study a real life problem of a specific steel company was considered and recommendations were gathered. To extend the proposed methodology:
    - Other structural steel manufacturing companies and several companies in manufacturing industry can be focused on and their client order prioritization and facility layout design problems can be solved.
    - Comparison of those results with those of this study can be interesting.

- The research objective of prioritization is defining the criteria for the evaluation of customer orders, prioritizing them, and prioritizing orders. For prioritization of criteria, direct or indirect methods such as point allocation, conjoint analysis can be used. If interconnections among criteria and alternatives are neglected, other MCDM tools can be applied for the prioritization of client orders.
- The research objective of facility design is developing a mathematical model and solving it to find the optimum solution in terms of handling cost.
    - For the formulation of the mathematical model other methods like QAP, fuzzy logics can be used.
    - For the resolution of the model, other solvers like Bonmin can be used.
    - The results can be compared also.
    - Furthermore, a sensitivity analysis can be used to determine how the result will be impacted by the different values of parameters for facility layout design mathematical model.
- If research objective is changed, considering the network structure of the problem on hand, FCM can be used to map the determined factors (corresponds to the criteria in this study) and their effects both on the objective of the structural steel manufacturing company and on each other. This model will allow the DMs to visualize and to simulate the effects of any activation of each factor or factor group. In addition, these factors can be analyzed by using The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method and the results can be compared with FCM's. System Dynamics is the other tool, which can be utilized for visualization of the causal relationships and interdependence of the determined factors.

All these methodologies will be an extension of this study and create a contribution to the literature of the construction and especially to the structural steel industry.

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APPENDICES

APPENDIX A: A Part of Questionnaire

APPENDIX B: Geometric Means of DMs

APPENDIX C: Supermatrix of the decision model

APPENDIX A

The below questionnaire, of which subject is “The most suitable order(s) under limited workforce and manufacturing capacities for the company under consideration” is prepared to collect data. For the reliability of this study, please answer **all the questions completely**. Thank you for your interest, your time and your valuable contributions.

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Before starting the questionnaire, it is necessary to read the following brief explanations about the criteria to be used in the questionnaire.

Potential profit rate per unit of time: *Potential profitability ratio should be considered per unit of time rather than total profitability.*

(A demand with higher profit margin but a longer operation time may not be profitable when it is compared with a demand with lower profit margin but a shorter operation time.)

Compatibility of potential order with the available capacity*:* The suitability level of the potential order in terms of companies' limited capacity

Level of potential future order with higher profit: The level of possibility of receiving a future demand that is much more profitable than the one in consideration

Customer credit of future business opportunity: The level of being a loyal customer of the manufacturing company

Negotiability level of production schedule for the order: The level of flexibility of the project in terms of project schedule

Assessment Method

*On the following pages, you will be asked to specify the importance of the factors that may affect **"the most suitable order to be selected under the current production and workforce capacity constraints for the company"**. During the mentioned evaluation; the factors will be compared in pairs, and their importance will be indicated on the scale as a result of the comparison based on the given description.*

Assessment Examples

Sample Question

Please compare the below projects in terms of their effect on "**potential profit rate per unit of time"** and specify which project how much important than the another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca

Sample Assessment 1

If you think that Administrative Building in Gemlik and Shopping Center in Sapanca has equal importance in terms of their effect on "potential profit rate per unit of time", you should select 1 in the middle.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

Administrative Building in Gemlik	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Shopping Center in Sapanca

Sample Assessment 2

If you think that Administrative Building in Gemlik has a very strongly more importance than Shopping Center in Sapanca in terms of their effect on "potential profit rate per unit of time", you should select 7 in left hand side.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

Administrative Building in Gemlik	9	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca

Sample Assessment 3

If you think that Administrative Shopping Center in Sapanca has an importance between strongly more and moderately more when it is compared with Building in Gemlik in terms of their effect on "potential profit rate per unit of time", you should select 4in right hand side.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	9	Shopping Center in Sapanca

Please compare the below factors in terms of their effect on "Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration" and specify which factor how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The compatibility of potential order with the available capacity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
Customer credit of future business opportunity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order

Please compare the below projects in terms of their effect on "**potential profit rate per unit of time"** and specify which project how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factory in Pakistan
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Housing Project in Algeria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia

Please compare the below projects in terms of their effect on **“compatibility of potential order with the available capacity”** and specify which project how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factory in Pakistan
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Housing Project in Algeria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia

Please compare the below projects in terms of their effect on **"level of potential future order with higher profit"** and specify which project how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factory in Pakistan
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Housing Project in Algeria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia

Please compare the below projects in terms of their effect on **“customer credit of future business opportunity”** and specify which project how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factory in Pakistan
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Housing Project in Algeria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia

Please compare the below projects in terms of their effect on **“negotiability level of production schedule for the order”** and specify which project how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factory in Pakistan
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Housing Project in Algeria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shopping Center in Sapanca
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Administrative Building in Gemlik	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compressor Station in Eskisehir
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Compressor Station in Eskisehir	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Administrative Building in Gemlik
Factory in Pakistan	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Housing Project in Algeria
Shopping Center in Sapanca	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia
Water Sport Center in Cengelkoy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	City Hall Project in Lazika, Georgia

Please compare the below factors in terms of their effect on **"Water Sport Center in Cengelkoy"** and specify which factor how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The compatibility of potential order with the available capacity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
Customer credit of future business opportunity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order

Please compare the below factors in terms of their effect on **"Factory in Pakistan"** and specify which factor how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The compatibility of potential order with the available capacity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
Customer credit of future business opportunity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order

Please compare the below factors in terms of their effect on **“Shopping Center in Sapanca”** and specify which factor how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The compatibility of potential order with the available capacity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
Customer credit of future business opportunity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order

Please compare the below factors in terms of their effect on **“Compressor Station in Eskisehir”** and specify which factor how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The compatibility of potential order with the available capacity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
Customer credit of future business opportunity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order

Please compare the below factors in terms of their effect on **"Administrative Building in Gemlik"** and specify which factor how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The compatibility of potential order with the available capacity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
Customer credit of future business opportunity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order

Please compare the below factors in terms of their effect on **"Housing Project in Algeria"** and specify which factor how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more
9=Overwhelming dominance

The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The compatibility of potential order with the available capacity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
Customer credit of future business opportunity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order

Please compare the below factors in terms of their effect on **"City Hall Project in Lazika, Georgia"** and specify which factor how much important than another.

1=Equal 3= Moderately more 5=Strongly more 7=Very strongly more 9=Overwhelming dominance

The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The compatibility of potential order with the available capacity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
Customer credit of future business opportunity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The level of potential future order with higher profit
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The level of potential future order with higher profit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer credit of future business opportunity
The compatibility of potential order with the available capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order
The potential profit rate per unit of time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	The negotiability level of production schedule for the order

APPENDIX B

Table B.1: Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The potential profit rate per unit of time	The compatibility of potential order with the available capacity	Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration	4	5	4	4.31
The compatibility of potential order with the available capacity	The level of potential future order with higher profit	Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration	1/2	1/3	1	1/1.82
The level of potential future order with higher profit	Customer credit of future business opportunity	Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration	3	3	4	3.30

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Customer credit of future business opportunity	The negotiability level of production schedule for the order	Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration	1/4	1/4	1/3	1/3.63
The potential profit rate per unit of time	The level of potential future order with higher profit	Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration	5	4	5	4.64
The compatibility of potential order with the available capacity	Customer credit of future business opportunity	Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration	4	5	5	4.64
The level of potential future order with higher profit	The negotiability level of production schedule for the order	Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration	4	3	2	2.88
The potential profit rate per unit of time	Customer credit of future business opportunity	Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration	5	4	4	4.31

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The compatibility of potential order with the available capacity	The negotiability level of production schedule for the order	Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration	1/3	3	4	1.59
The potential profit rate per unit of time	The negotiability level of production schedule for the order	Selecting the most suitable order under limited workforce and manufacturing capacities for the company under consideration	5	6	7	5.94
Water Sport Center in Cengelkoy	Factory in Pakistan	potential profit rate per unit of time	1/4	1/4	1/6	1/4.58
Factory in Pakistan	Shopping Center in Sapanca	potential profit rate per unit of time	6	6	7	6.32
Shopping Center in Sapanca	Compressor Station in Eskisehir	potential profit rate per unit of time	1/3	1/3	3	1/1.44
Compressor Station in Eskisehir	Administrative Building in Gemlik	potential profit rate per unit of time	1/6	1/5	1/6	1/5.65
Administrative Building in Gemlik	Housing Project in Algeria	potential profit rate per unit of time	3	3	2	2.62

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Housing Project in Algeria	City Hall Project in Lazika, Georgia	potential profit rate per unit of time	4	2	1/2	1.59
Water Sport Center in Cengelkoy	Shopping Center in Sapanca	potential profit rate per unit of time	4	4	3	3.63
Factory in Pakistan	Compressor Station in Eskisehir	potential profit rate per unit of time	6	6	9	6.87
Shopping Center in Sapanca	Administrative Building in Gemlik	potential profit rate per unit of time	1/6	1/5	1/4	1/4.93
Compressor Station in Eskisehir	Housing Project in Algeria	potential profit rate per unit of time	1/4	1/4	1/3	1/3.63
Administrative Building in Gemlik	City Hall Project in Lazika, Georgia	potential profit rate per unit of time	4	4	1	2.52
Water Sport Center in Cengelkoy	Compressor Station in Eskisehir	potential profit rate per unit of time	3	4	3	3.30
Factory in Pakistan	Administrative Building in Gemlik	potential profit rate per unit of time	1/3	1/2	4	1/1.45
Shopping Center in Sapanca	Housing Project in Algeria	potential profit rate per unit of time	1/4	1/3	1/3	1/3.01

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Compressor Station in Eskisehir	City Hall Project in Lazika, Georgia	potential profit rate per unit of time	1/3	1/4	1/4	1/3.63
Water Sport Center in Cengelkoy	Administrative Building in Gemlik	potential profit rate per unit of time	1/4	1/5	1/4	1/4.31
Factory in Pakistan	Housing Project in Algeria	potential profit rate per unit of time	3	2	4	2.88
Shopping Center in Sapanca	City Hall Project in Lazika, Georgia	potential profit rate per unit of time	1/3	1/4	1/5	1/3.92
Water Sport Center in Cengelkoy	Housing Project in Algeria	potential profit rate per unit of time	1/3	1/3	1/3	0.33
Shopping Center in Sapanca	City Hall Project in Lazika, Georgia	potential profit rate per unit of time	1/4	1/3	1/6	1/4.16
Water Sport Center in Cengelkoy	City Hall Project in Lazika, Georgia	potential profit rate per unit of time	1/2	1/3	1/4	½.89
Water Sport Center in Cengelkoy	Factory in Pakistan	compatibility of potential order with the available capacity	1/4	1/3	1/5	1/3.92
Factory in Pakistan	Shopping Center in Sapanca	compatibility of potential order with the available capacity	4	2	8	4.00

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Shopping Center in Sapanca	Compressor Station in Eskisehir	compatibility of potential order with the available capacity	1/3	1/3	1/3	1/3.00
Compressor Station in Eskisehir	Administrative Building in Gemlik	compatibility of potential order with the available capacity	1/2	1/5	1/5	1/3.68
Administrative Building in Gemlik	Housing Project in Algeria	compatibility of potential order with the available capacity	1	3	1/4	1/1.10
Housing Project in Algeria	City Hall Project in Lazika, Georgia	compatibility of potential order with the available capacity	2	4	4	3.17
Water Sport Center in Cengelkoy	Shopping Center in Sapanca	compatibility of potential order with the available capacity	4	5	3	3.91
Factory in Pakistan	Compressor Station in Eskisehir	compatibility of potential order with the available capacity	4	6	8	5.77
Shopping Center in Sapanca	Administrative Building in Gemlik	compatibility of potential order with the available capacity	1/3	1/4	1/3	1/3.3
Compressor Station in Eskisehir	Housing Project in Algeria	compatibility of potential order with the available capacity	2	1/3	1/5	1/1.96

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Administrative Building in Gemlik	City Hall Project in Lazika, Georgia	compatibility of potential order with the available capacity	1/2	3	2	1.44
Water Sport Center in Cengelkoy	Compressor Station in Eskisehir	compatibility of potential order with the available capacity	3	4	5	3.91
Factory in Pakistan	Administrative Building in Gemlik	compatibility of potential order with the available capacity	3	1/2	7	2.19
Shopping Center in Sapanca	Housing Project in Algeria	compatibility of potential order with the available capacity	1/3	1/3	1/5	1/3.56
Compressor Station in Eskisehir	City Hall Project in Lazika, Georgia	compatibility of potential order with the available capacity	1/2	1/2	1/4	1/2.52
Water Sport Center in Cengelkoy	Administrative Building in Gemlik	compatibility of potential order with the available capacity	1/3	1/3	1/3	1/3.00
Factory in Pakistan	Housing Project in Algeria	compatibility of potential order with the available capacity	3	2	2	2.29
Shopping Center in Sapanca	City Hall Project in Lazika, Georgia	compatibility of potential order with the available capacity	1/3	1/3	1/4	1/3.30

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Water Sport Center in Cengelkoy	Housing Project in Algeria	compatibility of potential order with the available capacity	2	1/3	1/3	1/1.65
Shopping Center in Sapanca	City Hall Project in Lazika, Georgia	compatibility of potential order with the available capacity	1/2	1/2	1/4	1/2.52
Water Sport Center in Cengelkoy	City Hall Project in Lazika, Georgia	compatibility of potential order with the available capacity	1/2	2	1/3	1/1.44
Water Sport Center in Cengelkoy	Factory in Pakistan	level of potential future order with higher profit	4	4	4	4.00
Factory in Pakistan	Shopping Center in Sapanca	level of potential future order with higher profit	1/8	1/7	1/9	1/7.96
Shopping Center in Sapanca	Compressor Station in Eskisehir	level of potential future order with higher profit	6	3	3	3.78
Compressor Station in Eskisehir	Administrative Building in Gemlik	level of potential future order with higher profit	8	4	8	6.35
Administrative Building in Gemlik	Housing Project in Algeria	level of potential future order with higher profit	1/4	1/2	1/2	1/2.52
Housing Project in Algeria	City Hall Project in Lazika, Georgia	level of potential future order with higher profit	1/3	1/2	1/2	1/2.29

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Water Sport Center in Cengelkoy	Shopping Center in Sapanca	level of potential future order with higher profit	1/6	1/5	1/5	1/5.31
Factory in Pakistan	Compressor Station in Eskisehir	level of potential future order with higher profit	1/6	1/4	1/7	1/5.52
Shopping Center in Sapanca	Administrative Building in Gemlik	level of potential future order with higher profit	6	6	9	6.87
Compressor Station in Eskisehir	Housing Project in Algeria	level of potential future order with higher profit	5	4	7	5.19
Administrative Building in Gemlik	City Hall Project in Lazika, Georgia	level of potential future order with higher profit	1/4	1/3	1/3	1/3.30
Water Sport Center in Cengelkoy	Compressor Station in Eskisehir	level of potential future order with higher profit	1/3	1/3	1/4	1/3.31
Factory in Pakistan	Administrative Building in Gemlik	level of potential future order with higher profit	1	1	2	1.26
Shopping Center in Sapanca	Housing Project in Algeria	level of potential future order with higher profit	6	5	6	5.65
Compressor Station in Eskisehir	City Hall Project in Lazika, Georgia	level of potential future order with higher profit	4	5	7	5.19

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Water Sport Center in Cengelkoy	Administrative Building in Gemlik	level of potential future order with higher profit	4	4	6	4.58
Factory in Pakistan	Housing Project in Algeria	level of potential future order with higher profit	1/2	1/2	3	1/1.10
Shopping Center in Sapanca	City Hall Project in Lazika, Georgia	level of potential future order with higher profit	6	4	6	5.24
Water Sport Center in Cengelkoy	Housing Project in Algeria	level of potential future order with higher profit	2	2	4	2.52
Shopping Center in Sapanca	City Hall Project in Lazika, Georgia	level of potential future order with higher profit	6	4	5	4.93
Water Sport Center in Cengelkoy	City Hall Project in Lazika, Georgia	level of potential future order with higher profit	5	2	3	3.11
Water Sport Center in Cengelkoy	Factory in Pakistan	customer credit of future business opportunity	4	3	5	3.91
Factory in Pakistan	Shopping Center in Sapanca	customer credit of future business opportunity	1/8	1/7	1/7	1/7.32
Shopping Center in Sapanca	Compressor Station in Eskisehir	customer credit of future business opportunity	6	6	6	6.00

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Compressor Station in Eskisehir	Administrative Building in Gemlik	customer credit of future business opportunity	1/7	1/8	1/9	1/7.96
Administrative Building in Gemlik	Housing Project in Algeria	customer credit of future business opportunity	3	3	1	2.08
Housing Project in Algeria	City Hall Project in Lazika, Georgia	customer credit of future business opportunity	6	6	7	6.32
Water Sport Center in Cengelkoy	Shopping Center in Sapanca	customer credit of future business opportunity	1/4	1/6	1/3	1/4.16
Factory in Pakistan	Compressor Station in Eskisehir	customer credit of future business opportunity	1/2	2	2	1.26
Shopping Center in Sapanca	Administrative Building in Gemlik	customer credit of future business opportunity	1/3	1/2	1/2	1/2.29
Compressor Station in Eskisehir	Housing Project in Algeria	customer credit of future business opportunity	1/4	4	1/6	1/1.82
Administrative Building in Gemlik	City Hall Project in Lazika, Georgia	customer credit of future business opportunity	7	6	8	6.95
Water Sport Center in Cengelkoy	Compressor Station in Eskisehir	customer credit of future business opportunity	4	5	3	3.91

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Factory in Pakistan	Administrative Building in Gemlik	customer credit of future business opportunity	1/3	1/5	1/5	¼.22
Shopping Center in Sapanca	Housing Project in Algeria	customer credit of future business opportunity	4	1/2	1	1.26
Compressor Station in Eskisehir	City Hall Project in Lazika, Georgia	customer credit of future business opportunity	3	3	3	3.00
Water Sport Center in Cengelkoy	Administrative Building in Gemlik	customer credit of future business opportunity	1/4	1/4	1/3	1/3.63
Factory in Pakistan	Housing Project in Algeria	customer credit of future business opportunity	1/3	1/4	1/4	1/3.63
Shopping Center in Sapanca	City Hall Project in Lazika, Georgia	customer credit of future business opportunity	6	5	6	5.65
Water Sport Center in Cengelkoy	Housing Project in Algeria	customer credit of future business opportunity	1/3	1/3	1/5	1/3.56
Shopping Center in Sapanca	City Hall Project in Lazika, Georgia	customer credit of future business opportunity	7	4	7	5.81
Water Sport Center in Cengelkoy	City Hall Project in Lazika, Georgia	customer credit of future business opportunity	4	4	4	4.00

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Water Sport Center in Cengelkoy	Factory in Pakistan	negotiability level of production schedule for the order	4	4	6	4.58
Factory in Pakistan	Shopping Center in Sapanca	negotiability level of production schedule for the order	1/6	1/5	1/7	1/5.94
Shopping Center in Sapanca	Compressor Station in Eskisehir	negotiability level of production schedule for the order	7	6	4	5.52
Compressor Station in Eskisehir	Administrative Building in Gemlik	negotiability level of production schedule for the order	3	4	3	3.30
Administrative Building in Gemlik	Housing Project in Algeria	negotiability level of production schedule for the order	1/4	3	1/4	1/1.75
Housing Project in Algeria	City Hall Project in Lazika, Georgia	negotiability level of production schedule for the order	3	4	4	3.63
Water Sport Center in Cengelkoy	Shopping Center in Sapanca	negotiability level of production schedule for the order	1/4	3	1/3	1/1.59
Factory in Pakistan	Compressor Station in Eskisehir	negotiability level of production schedule for the order	1/4	3	1/2	1/1.39

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Shopping Center in Sapanca	Administrative Building in Gemlik	negotiability level of production schedule for the order	6	5	6	5.65
Compressor Station in Eskisehir	Housing Project in Algeria	negotiability level of production schedule for the order	1/2	1/2	1/3	1/2.29
Administrative Building in Gemlik	City Hall Project in Lazika, Georgia	negotiability level of production schedule for the order	1/2	1/2	2	1/1.26
Water Sport Center in Cengelkoy	Compressor Station in Eskisehir	negotiability level of production schedule for the order	1/2	1/2	3	1/1.10
Factory in Pakistan	Administrative Building in Gemlik	negotiability level of production schedule for the order	2	1	1	1.26
Shopping Center in Sapanca	Housing Project in Algeria	negotiability level of production schedule for the order	3	4	2	2.88
Compressor Station in Eskisehir	City Hall Project in Lazika, Georgia	negotiability level of production schedule for the order	4	3	3	3.30
Water Sport Center in Cengelkoy	Administrative Building in Gemlik	negotiability level of production schedule for the order	3	4	4	3.63

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Factory in Pakistan	Housing Project in Algeria	negotiability level of production schedule for the order	1/2	1/3	1/3	1/2.62
Shopping Center in Sapanca	City Hall Project in Lazika, Georgia	negotiability level of production schedule for the order	4	5	5	4.64
Water Sport Center in Cengelkoy	Housing Project in Algeria	negotiability level of production schedule for the order	3	1/2	2	1.44
Shopping Center in Sapanca	City Hall Project in Lazika, Georgia	negotiability level of production schedule for the order	6	4	5	4.93
Water Sport Center in Cengelkoy	City Hall Project in Lazika, Georgia	negotiability level of production schedule for the order	5	3	4	3.91
The potential profit rate per unit of time	The compatibility of potential order with the available capacity	Water Sport Center in Cengelkoy	4	2	6	3.63
The compatibility of potential order with the available capacity	The level of potential future order with higher profit	Water Sport Center in Cengelkoy	2	1/3	1/4	1/1.82

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The level of potential future order with higher profit	Customer credit of future business opportunity	Water Sport Center in Cengelkoy	1/3	1/2	1/5	1/3.11
Customer credit of future business opportunity	The negotiability level of production schedule for the order	Water Sport Center in Cengelkoy	3	3	4	3.30
The potential profit rate per unit of time	The level of potential future order with higher profit	Water Sport Center in Cengelkoy	5	4	1/3	1.88
The compatibility of potential order with the available capacity	Customer credit of future business opportunity	Water Sport Center in Cengelkoy	2	1/2	1/4	1/1.59
The level of potential future order with higher profit	The negotiability level of production schedule for the order	Water Sport Center in Cengelkoy	1/3	1/2	1/5	1/3.11

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The potential profit rate per unit of time	Customer credit of future business opportunity	Water Sport Center in Cengelkoy	1/3	2	1/3	1/1.65
The compatibility of potential order with the available capacity	The negotiability level of production schedule for the order	Water Sport Center in Cengelkoy	1/2	1/3	1/2	1/2.30
The potential profit rate per unit of time	The negotiability level of production schedule for the order	Water Sport Center in Cengelkoy	2	1/2	5	1.71
The potential profit rate per unit of time	The compatibility of potential order with the available capacity	Factory in Pakistan	6	4	5	4.93
The compatibility of potential order with the available capacity	The level of potential future order with higher profit	Factory in Pakistan	7	3	4	4.38
The level of potential future order with higher profit	Customer credit of future business opportunity	Factory in Pakistan	1/3	1/2	1/3	1/2.62

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
Customer credit of future business opportunity	The negotiability level of production schedule for the order	Factory in Pakistan	3	3	4	3.30
The potential profit rate per unit of time	The level of potential future order with higher profit	Factory in Pakistan	5	5	6	5.31
The compatibility of potential order with the available capacity	Customer credit of future business opportunity	Factory in Pakistan	4	4	1/2	2.00
The level of potential future order with higher profit	The negotiability level of production schedule for the order	Factory in Pakistan	1/3	1/3	1/3	1/3.00
The potential profit rate per unit of time	Customer credit of future business opportunity	Factory in Pakistan	4	2	4	3,17
The compatibility of potential order with the available capacity	The negotiability level of production schedule for the order	Factory in Pakistan	2	2	2	2,00

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The potential profit rate per unit of time	The negotiability level of production schedule for the order	Factory in Pakistan	3	3	3	3.00
The potential profit rate per unit of time	The compatibility of potential order with the available capacity	Shopping Center in Sapanca	1/4	1/3	1/4	1/3.63
The compatibility of potential order with the available capacity	The level of potential future order with higher profit	Shopping Center in Sapanca	1/6	1/6	1/6	1/6.00
The level of potential future order with higher profit	Customer credit of future business opportunity	Shopping Center in Sapanca	1/8	1/3	1/3	1/4.16
Customer credit of future business opportunity	The negotiability level of production schedule for the order	Shopping Center in Sapanca	4	1/2	3	1.82
The potential profit rate per unit of time	The level of potential future order with higher profit	Shopping Center in Sapanca	1/3	4	1/7	1/1.74

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The compatibility of potential order with the available capacity	Customer credit of future business opportunity	Shopping Center in Sapanca	1/6	5	1/3	1/1.53
The level of potential future order with higher profit	The negotiability level of production schedule for the order	Shopping Center in Sapanca	1/5	4	1/2	1/1.36
The potential profit rate per unit of time	Customer credit of future business opportunity	Shopping Center in Sapanca	1/6	1/3	1/2	0.30
The compatibility of potential order with the available capacity	The negotiability level of production schedule for the order	Shopping Center in Sapanca	1/5	1/2	1/4	0.29
The potential profit rate per unit of time	The negotiability level of production schedule for the order	Shopping Center in Sapanca	1/4	1/3	1/3	0.30

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The potential profit rate per unit of time	The compatibility of potential order with the available capacity	Compressor Station in Eskisehir	3	2	1/3	1.26
The compatibility of potential order with the available capacity	The level of potential future order with higher profit	Compressor Station in Eskisehir	1/4	1/3	1/5	1/3.91
The level of potential future order with higher profit	Customer credit of future business opportunity	Compressor Station in Eskisehir	1/3	2	4	1.39
Customer credit of future business opportunity	The negotiability level of production schedule for the order	Compressor Station in Eskisehir	2	2	1/4	1.00
The potential profit rate per unit of time	The level of potential future order with higher profit	Compressor Station in Eskisehir	1/3	1/4	1/4	1/3.63
The compatibility of potential order with the available capacity	Customer credit of future business opportunity	Compressor Station in Eskisehir	1/3	1/2	1/2	1/2.29

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The level of potential future order with higher profit	The negotiability level of production schedule for the order	Compressor Station in Eskisehir	4	1/2	2	1.59
The potential profit rate per unit of time	Customer credit of future business opportunity	Compressor Station in Eskisehir	2	2	3	2.29
The compatibility of potential order with the available capacity	The negotiability level of production schedule for the order	Compressor Station in Eskisehir	1/3	1/2	1/3	1/2.62
The potential profit rate per unit of time	The negotiability level of production schedule for the order	Compressor Station in Eskisehir	2	2	1/4	1.00
The potential profit rate per unit of time	The compatibility of potential order with the available capacity	Administrative Building in Gemlik	7	5	6	5.94
The compatibility of potential order with the available capacity	The level of potential future order with higher profit	Administrative Building in Gemlik	5	4	2	3.42

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The level of potential future order with higher profit	Customer credit of future business opportunity	Administrative Building in Gemlik	1/6	1/6	1/8	1/6.60
Customer credit of future business opportunity	The negotiability level of production schedule for the order	Administrative Building in Gemlik	8	6	6	6.60
The potential profit rate per unit of time	The level of potential future order with higher profit	Administrative Building in Gemlik	6	7	5	5.94
The compatibility of potential order with the available capacity	Customer credit of future business opportunity	Administrative Building in Gemlik	1/6	1/4	1/6	1/5.24
The level of potential future order with higher profit	The negotiability level of production schedule for the order	Administrative Building in Gemlik	1/2	1/3	1/4	½.88
The potential profit rate per unit of time	Customer credit of future business opportunity	Administrative Building in Gemlik	1/3	1/6	1/3	1/3.78

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The compatibility of potential order with the available capacity	The negotiability level of production schedule for the order	Administrative Building in Gemlik	3	3	1/2	1.65
The potential profit rate per unit of time	The negotiability level of production schedule for the order	Administrative Building in Gemlik	6	5	2	3.91
The potential profit rate per unit of time	The compatibility of potential order with the available capacity	Housing Project in Algeria	4	3	4	3.63
The compatibility of potential order with the available capacity	The level of potential future order with higher profit	Housing Project in Algeria	2	2	3	2.29
The level of potential future order with higher profit	Customer credit of future business opportunity	Housing Project in Algeria	1/6	1/4	1/5	1/4.93
Customer credit of future business opportunity	The negotiability level of production schedule for the order	Housing Project in Algeria	7	3	3	3.98
The potential profit rate per unit of time	The level of potential future order with higher profit	Housing Project in Algeria	6	6	4	5.24

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The compatibility of potential order with the available capacity	Customer credit of future business opportunity	Housing Project in Algeria	1/5	1/4	1/5	1/4.64
The level of potential future order with higher profit	The negotiability level of production schedule for the order	Housing Project in Algeria	1/2	1/5	1/4	1/3.42
The potential profit rate per unit of time	Customer credit of future business opportunity	Housing Project in Algeria	1/3	1/3	1/2	1/2.62
The compatibility of potential order with the available capacity	The negotiability level of production schedule for the order	Housing Project in Algeria	2	1/2	1/3	1/1.44
The potential profit rate per unit of time	The negotiability level of production schedule for the order	Housing Project in Algeria	3	4	2	2.88
The potential profit rate per unit of time	The compatibility of potential order with the available capacity	City Hall Project in Lazika, Georgia	6	3	5	4.48
The compatibility of potential order with the available capacity	The level of potential future order with higher profit	City Hall Project in Lazika, Georgia	1/2	2	2	1.26

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The level of potential future order with higher profit	Customer credit of future business opportunity	City Hall Project in Lazika, Georgia	3	1/2	1/2	1/1.10
Customer credit of future business opportunity	The negotiability level of production schedule for the order	City Hall Project in Lazika, Georgia	2	1/4	1/4	1/2.00
The potential profit rate per unit of time	The level of potential future order with higher profit	City Hall Project in Lazika, Georgia	5	6	6	5.65
The compatibility of potential order with the available capacity	Customer credit of future business opportunity	City Hall Project in Lazika, Georgia	2	2	4	2.52
The level of potential future order with higher profit	Customer credit of future business opportunity	City Hall Project in Lazika, Georgia	3	1/2	1/2	1/1.10
The level of potential future order with higher profit	The negotiability level of production schedule for the order	City Hall Project in Lazika, Georgia	2	1/3	1/3	1/1.65
The potential profit rate per unit of time	Customer credit of future business opportunity	City Hall Project in Lazika, Georgia	3	4	6	4.16

Table B.1 (continued) : Geometric means of DMs.

Pairwise Comparison Of		With Respect to the Effect On	Factory Manager	Technical Office Manager	Business Development Manager	Geometric Mean
The compatibility of potential order with the available capacity	The negotiability level of production schedule for the order	City Hall Project in Lazika, Georgia	2	2	2	2.00
The potential profit rate per unit of time	The negotiability level of production schedule for the order	City Hall Project in Lazika, Georgia	4	4	4	4.00

APPENDIX C

	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Crit. 1	Crit. 2	Crit. 3	Crit. 4	Crit. 5
Alt. 1	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.069849	0.106553	0.126776	0.105834	0.183981
Alt. 2	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.216561	0.254767	0.071086	0.059268	0.072841
Alt. 3	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.034144	0.038889	0.421865	0.249923	0.382007
Alt. 4	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.036554	0.057925	0.240631	0.041631	0.124405
Alt. 5	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.271589	0.174629	0.031567	0.321895	0.041412
Alt. 6	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.144129	0.187371	0.050616	0.195823	0.149769
Alt. 7	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.227174	0.179866	0.057460	0.025626	0.045585
Crit. 1	0.251384	0.488380	0.057538	0.121234	0.275923	0.274364	0.520490	0.000000	0.000000	0.000000	0.000000	0.000000
Crit. 2	0.098845	0.195517	0.086951	0.087831	0.092099	0.091471	0.170666	0.000000	0.000000	0.000000	0.000000	0.000000
Crit. 3	0.110984	0.052956	0.223480	0.371643	0.040374	0.053012	0.092473	0.000000	0.000000	0.000000	0.000000	0.000000
Crit. 4	0.350744	0.163830	0.412256	0.217456	0.518420	0.455912	0.086402	0.000000	0.000000	0.000000	0.000000	0.000000
Crit. 5	0.188044	0.099318	0.219775	0.201836	0.073184	0.125242	0.129970	0.000000	0.000000	0.000000	0.000000	0.000000

Figure C.1: Supermatrix of the decision model.

APPENDIX D

In this appendix, the equations based on Table 3.5 stated in Chapter 3 are explained as below.

As it is seen in Table 3.5 the total flow from workstation *1* to workstation *2* and *3* is 5,500 tons.

$$f_{1,2} + f_{1,3} = 5500\ ton \tag{D.1}$$

The total of the flow that gets in to one workstation should not exceed the capacity of the workstation (machine). The capacity limitations of 2nd and 3rd workstations are given below:

$$f_{1,2} \leq 3000\ tons \tag{D.2}$$

$$f_{1,3} \leq 4000\ tons \tag{D.3}$$

As it is seen in Table 3.5 the total flow from workstation *2* and *3* to workstation *4* and *5* is 1,050 tons.

$$f_{2,4} + f_{3,4} + f_{2,5} + f_{3,5} = 1050\ tons \tag{D.4}$$

As it is seen in Table 3.5 the total flow from workstation *2* and *3* to workstation *6* and *7* is 2,820 tons.

$$f_{2,6} + f_{3,6} + f_{2,7} + f_{3,7} = 2820\ tons \tag{D.5}$$

As it is seen in Table 3.5 the total flow from workstation *2* and *3* to workstation *8* is 520 tons.

$$f_{2,8} + f_{3,8} = 520\ tons \tag{D.6}$$

As it is seen in Table 3.5 the total flow from workstation *2* and *3* to workstation *9* is 405 tons.

$$f_{2,9} + f_{3,9} = 405\ tons \quad \text{(D.7)}$$

As it is seen in Table 3.5 the total flow from workstation *2* and *3* to workstation *10* is 310 tons.

$$f_{2,10} + f_{3,10} = 310\ tons \quad \text{(D.8)}$$

As it is seen in Table 3.5 the total flow from workstation *2* and *3* to workstation *11* is 395 tons.

$$f_{2,11} + f_{3,11} = 395\ tons \quad \text{(D.9)}$$

The capacity limitations of 4^{th}, 5^{th} , 6^{th}, and 7^{th} workstations are given below:

$$f_{2,4} + f_{3,4} \leq 600\ tons \quad \text{(D.10)}$$

$$f_{2,5} + f_{3,5} \leq 750\ tons \quad \text{(D.11)}$$

$$f_{2,6} + f_{3,6} \leq 1950\ tons \quad \text{(D.12)}$$

$$f_{2,7} + f_{3,7} \leq 2050\ tons \quad \text{(D.13)}$$

The capacity limitations of 8^{th},9^{th}, 10^{th} and 11^{st} workstations are given below. These constraints are redundant because the incoming flows are less than the capacities. Therefore there is no need to take attention of those in the model.

$$f_{2,8} + f_{3,8} \leq 650\ tons \quad \text{(D.14)}$$

$$f_{2,9} + f_{3,9} \leq 550\ tons \quad \text{(D.15)}$$

$$f_{2,10} + f_{3,10} \leq 400\ tons \quad \text{(D.16)}$$

$$f_{2,11} + f_{3,11} \leq 450\ tons \quad \text{(D.17)}$$

Besides the income and outcome flows of a workstation should be equal:

$$f_{1,2} = f_{2,4} + f_{2,5} + f_{2,6} + f_{2,7} + f_{2,8} + f_{2,9} + f_{2,10} + f_{2,11} \quad \text{(D.18)}$$

$$f_{1,3} = f_{3,4} + f_{3,5} + f_{3,6} + f_{3,7} + f_{3,8} + f_{3,9} + f_{3,10} + f_{3,11} \quad \text{(D.19)}$$

As it is seen in Table 3.5 the total flow from workstation *4* and *5* to workstation *12* and *13* is 925 tons.

$$f_{4,12} + f_{5,12} + f_{4,13} + f_{5,13} = 925\ tons \tag{D.20}$$

As it is seen in Table 3.5 the total flow from workstation *4* and *5* to workstation *14* and *15* is 125 tons.

$$f_{4,14} + f_{5,14} + f_{4,15} + f_{5,15} = 125\ tons \tag{D.21}$$

As it is seen in Table 3.5 the total flow from workstation *6* and *7* to workstation *12* and *13* is 1,570 tons.

$$f_{6,12} + f_{7,12} + f_{6,13} + f_{7,13} = 1570\ tons \tag{D.22}$$

As it is seen in Table 3.5 the total flow from workstation *6* and *7* to workstation *14* and *15* is 1,250 tons.

$$f_{6,14} + f_{7,14} + f_{6,15} + f_{7,15} = 1250\ tons \tag{D.23}$$

As it is seen in Table 3.5 the total flow from workstation *8* to workstation *12* and *13* is 470 tons.

$$f_{8,12} + f_{8,13} = 470\ tons \tag{D.24}$$

As it is seen in Table 3.5 the total flow from workstation *8* to workstation *14* and *15* is 50 tons.

$$f_{8,14} + f_{8,15} = 50\ tons \tag{D.25}$$

As it is seen in Table 3.5 the total flow from workstation *9* to workstation *12* and *13* is 380 tons.

$$f_{9,12} + f_{9,13} = 380\ tons \tag{D.26}$$

As it is seen in Table 3.5 the total flow from workstation *9* to workstation *14* and *15* is 25 tons.

$$f_{9,14} + f_{9,15} = 25\ tons \tag{D.27}$$

As it is seen in Table 3.5 the total flow from workstation *10* to workstation *12* and *13* is 240 tons.

$$f_{10,12} + f_{10,13} = 240\ tons \quad \text{(D.28)}$$

As it is seen in Table 3.5 the total flow from workstation *10* to workstation *14* and *15* is 70 tons.

$$f_{10,14} + f_{10,15} = 70\ tons \quad \text{(D.29)}$$

As it is seen in Table 3.5 the total flow from workstation *11* to workstation *12* and *13* is 285 tons.

$$f_{11,12} + f_{11,13} = 285\ tons \quad \text{(D.30)}$$

As it is seen in Table 3.5 the total flow from workstation *11* to workstation *14* and *15* is 110 tons.

$$f_{11,14} + f_{11,15} = 110\ tons \quad \text{(D.31)}$$

The capacity limitations of 12nd, 13rd, 14th, and 15th workstations are given below:

$$f_{4,12} + f_{5,12} + f_{6,12} + f_{7,12} + f_{8,12} + f_{9,12} + f_{10,12} + f_{11,12} \le 2200\ tons \quad \text{(D.32)}$$

$$f_{4,13} + f_{5,13} + f_{6,13} + f_{7,13} + f_{8,13} + f_{9,13} + f_{10,13} + f_{11,13} \le 2400\ tons \quad \text{(D.33)}$$

$$f_{4,14} + f_{5,14} + f_{6,14} + f_{7,14} + f_{8,14} + f_{9,14} + f_{10,14} + f_{11,14} \le 1300\ tons \quad \text{(D.34)}$$

$$f_{4,15} + f_{5,15} + f_{6,15} + f_{7,15} + f_{8,15} + f_{9,15} + f_{10,15} + f_{11,15} \le 1500\ tons \quad \text{(D.35)}$$

Besides the income and outcome flows of a workstation should be equal:

$$f_{2,4} + f_{3,4} = f_{4,12} + f_{4,13} + f_{4,14} + f_{4,15} \quad \text{(D.36)}$$

$$f_{2,5} + f_{3,5} = f_{5,12} + f_{5,13} + f_{5,14} + f_{5,15} \quad \text{(D.37)}$$

$$f_{2,6} + f_{3,6} = f_{6,12} + f_{6,13} + f_{6,14} + f_{6,15} \quad \text{(D.38)}$$

$$f_{2,7} + f_{3,7} = f_{7,12} + f_{7,13} + f_{7,14} + f_{7,15} \quad \text{(D.39)}$$

$$f_{2,8} + f_{3,8} = f_{8,12} + f_{8,13} + f_{8,14} + f_{8,15} \quad \text{(D.40)}$$

$$f_{2,9} + f_{3,9} = f_{9,12} + f_{9,13} + f_{9,14} + f_{9,15} \quad \text{(D.41)}$$

$$f_{2,10} + f_{3,10} = f_{10,12} + f_{10,13} + f_{10,14} + f_{10,15} \quad \text{(D.42)}$$

$$f_{2,11} + f_{3,11} = f_{11,12} + f_{11,13} + f_{11,14} + f_{11,15} \quad \text{(D.43)}$$

As it is seen in Table 3.5 the total flow from workstation *12, 13, 14,* and *15* to workstation *16* is 5,500 tons.

$$f_{12,16} + f_{13,16} + f_{14,16} + f_{15,16} = 5500\ tons \quad \text{(D.44)}$$

The capacity limitation of 16th workstation is given below. This constraint is redundant because the incoming flows are less than the capacity. Therefore there is no need to take attention of it in the model.

$$f_{12,16} + f_{13,16} + f_{14,16} + f_{15,16} \leq 7000\ tons \quad \text{(D.45)}$$

Besides the income and outcome flows of a workstation should be equal:

$$f_{4,12} + f_{5,12} + f_{6,12} + f_{7,12} + f_{8,12} + f_{9,12} + f_{10,12} + f_{11,12} = f_{12,16} \quad \text{(D.46)}$$

$$f_{4,13} + f_{5,13} + f_{6,13} + f_{7,13} + f_{8,13} + f_{9,13} + f_{10,13} + f_{11,13} = f_{13,16} \quad \text{(D.47)}$$

$$f_{4,14} + f_{5,14} + f_{6,14} + f_{7,14} + f_{8,14} + f_{9,14} + f_{10,14} + f_{11,14} = f_{14,16} \quad \text{(D.48)}$$

$$f_{4,15} + f_{5,15} + f_{6,15} + f_{7,15} + f_{8,15} + f_{9,15} + f_{10,15} + f_{11,15} = f_{15,16} \quad \text{(D.49)}$$

As it is seen in Table 3.5 the total flow from workstation *16* to workstation *17, 18*, and *19* is 3.450 tons.

$$f_{16,17} + f_{16,18} + f_{16,19} = 3450\ tons \quad \text{(D.50)}$$

The capacity limitation of 17^{th}, 18^{th}, and 19^{th} workstation is given below:

$$f_{16,17} \leq 1600\ tons \quad \text{(D.51)}$$

$$f_{16,18} \leq 1600\ tons \quad \text{(D.52)}$$

$$f_{16,19} \leq 1600\ tons \tag{D.53}$$

As it is seen in Table 3.5 the total flow from workstation *16* to workstation *20* is 850 tons.

$$f_{16,20} = 850\ tons \tag{D.54}$$

The capacity limitation of 20th workstation is given below. This constraint is redundant because the incoming flows are less than the capacities. Therefore, there is no need to take attention of it in the model.

$$f_{16,20} \leq 1500\ tons \tag{D.55}$$

As it is seen in Table 3.5 the total flow from workstation *16* to workstation *21* is 1,200 tons.

$$f_{16,21} = 1200\ tons \tag{D.56}$$

The capacity limitation of 21^{st} workstation is given below:

$$f_{16,21} \leq 1500\ tons \tag{D.57}$$

Besides the income and outcome flows of a workstation should be equal:

$$f_{12,16} + f_{13,16} + f_{14,16} + f_{15,16} = f_{16,17} + f_{16,18} + f_{16,19} + f_{16,20} + f_{16,21} \tag{D.58}$$

As it is seen in Table 3.5 the total flow from workstation *17, 18* and *19* to workstation *22* is 3,450 tons.

$$f_{17,22} + f_{18,22} + f_{19,22} = 3450\ tons \tag{D.59}$$

As it is seen in Table 3.5 the total flow from workstation *20* to workstation *22* is 850 tons.

$$f_{20,22} = 850\ tons \tag{D.60}$$

As it is seen in Table 3.5 the total flow from workstation *21* to workstation *22* is 1,200 tons.

$$f_{21,22} = 1200\ tons \tag{D.61}$$

The capacity limitation of 22nd workstation is given below. This constraint is redundant because the incoming flows are less than the capacities. Therefore, there is no need to take attention of this in the model.

$$f_{17,22} + f_{18,22} + f_{19,22} \leq 6500\ tons \tag{D.62}$$

Besides the income and outcome flows of a workstation should be equal:

$$f_{16,17} = f_{17,22} \tag{D.63}$$

$$f_{16,18} = f_{18,22} \tag{D.64}$$

$$f_{16,19} = f_{19,22} \tag{D.65}$$

$$f_{16,20} = f_{20,22} \tag{D.66}$$

$$f_{16,21} = f_{21,22} \tag{D.67}$$

As it is seen in Table 3.5 the total flow from workstation *22* to workstation *23* is 5,500 tons.

$$f_{22,23} = 5500\ tons \tag{D.68}$$

The capacity limitation of 23^{rd} workstation is given below. This constraint is redundant because the incoming flow is less than the capacity. Therefore, there is no need to take attention of it in the model.

$$f_{22,23} \leq 8500\ tons \tag{D.69}$$

Besides the income and outcome flows of a workstation should be equal. This constraint is redundant because the incoming flows are already known the equality is already confirmed by other constraints. Therefore, there is no need to take attention of it in the model.

$$f_{17,22} + f_{18,22} + f_{19,22} + f_{20,22} + f_{21,22} = f_{22,23} \tag{D.70}$$

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