# A STUDY OF FACILITY LOCATION SELECTION AND FACILITY LAYOUT DESIGN PROBLEMS: APPLICATION IN HOME APPLIANCES SECTOR

(TESİS YERİ SEÇİMİ VE TASARIMI PROBLEMLERİ ÜZERİNE BİR ÇALIŞMA: EV ALETLERİ SEKTÖR UYGULAMASI)

by

**SEVİNÇ KOÇ, B.S.**

**Thesis**

Submitted in Partial Fulfillment

of the Requirements

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Facility layout design problem is one of the most significant optimization problems with strategic importance. Depending on its effect on performance measures it has always been a challenging field for researchers. In addition to layout design, facility layout selection is also a strategic decision for companies as it significantly affects current and future performance. The aim of this study is to solve above mentioned facility layout design and facility location selection problems in order to make a contribution to related literature.

I would like to thank to my project advisor Doç. Dr. Y. Esra ALBAYRAK for all her support and contribution she made during this project. I also would like to thank to company personnel who provides me all the necessary assistance during the procedure of data collecting.

I also wish to thank to my family and my friends for their encouragement and emotional support.

Sevinç KOÇ
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AHP: Analytic Hierarchy Process
ALDEP: Automated Layout Design Program
ANN: Artificial Neural Network
ANP: Analytic Network Process
CAD: Computer Aided Design
CORELAP: Computerized Relationship Layout Planning
CRAFT: Computerized Relative Allocation of Facilities Technique
DC: Distribution Center
DEA: Data Envelopment Analysis
ELECTRE: Elimination and Choice Translating Reality English
FLD: Facility Layout Design
FLS: Facility Layout Selection
FNIS: Fuzzy Negative Ideal Solution
FPIS: Fuzzy Positive Ideal Solution
FRS: Multifactor Rating System
FST: Fuzzy Set Theory
GDM: Group Decision Making Problem
MADM: Multiple Attribute Decision Making
MCDM: Multiple Criteria Decision Making
MIP: Mixed Integer Programming
QAP: Quadratic Assignment Problem
SAW: Simple Additive Weight Method
SWOT: Strengths, Weaknesses, Opportunities, Threads Analysis
TOPSIS: Technique for Order Preference by Similarity to Ideal Solution

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**ABSTRACT**

Facility location selection and facility layout design decisions have strategic importance for companies since they influence not only manufacturing and transportation costs but also productivity and lead times to a great extent. Additionally, they are considered as hard and complicated tasks with respect to their multi-objective nature and difficulties resulted from collecting necessary data. Therefore these two problems have always been an important subject of industrial engineering literature. The aim of this study is to solve facility layout design and facility location selection problems consecutively in a manufacturing company that locates in Tekirdağ region of Turkey. This company has six different factories in the same facility in which one of them, namely consumer products factory has been recently established. In the first part of the application, by the help of excel-based software program CRAFT, new layout design alternatives were proposed to decrease material flow costs. As a part of the study, current situation was analyzed, from-to and transport cost charts were then presented and best layout solution is aimed to be defined iteratively by the help of CRAFT software. Additionally, the company is considering about establishing a plastic injection factory in the future for producing some of the important plastic components not only to gain cost advantage but also to increase know-how. For this purpose, in the second part of the application; facility location selection problem is aimed to be solved by applying fuzzy TOPSIS and fuzzy AHP methods and the results are compared to each other.
*Key Words: Facility layout design; facility location selection; CRAFT; fuzzy AHP, fuzzy TOPSIS*

**RÉSUMÉ**

La sélection de location d'emplacement et les décisions de l'arrangement de plan (layout design) d'emplacement ont une importance stratégique pour les entreprises car elles influencent non seulement les coûts de fabrication et de transport, mais aussi une fois la productivité et le délai d'exécution dans une grande mesure. En outre, elles sont considérées comme compliquées en ce qui concerne leur nature multi-objective et difficultés résultant de recueillir les données nécessaires. Par conséquent, ces deux problèmes ont toujours été un sujet important de la littérature de l'ingénieure industrielle. Le but de cette étude est de résoudre les problèmes concernant la location d'emplacement et le layout design d'emplacement consécutivement dans une usine qui localise dans la région de Tekirdağ en Turquie. Cette entreprise dispose de six différentes usines dans le même établissement dans lequel, d'entre elles, à savoir usine de produits de consommation a été récemment établie. Dans la première partie de l'étude, à l'aide des logiciels Excel programment CRAFT, des alternatives pour un nouveau layout design, ont été proposées pour diminuer les coûts des flux de matières. Dans le cadre de l'étude, la situation actuelle a été analysée, la matrice de frome-to et celle de coûts de transport ont été ensuite présentées et la meilleure solution de layout, vise à se définir par itération à l'aide du software de CRAFT. De plus, l'entreprise envisage l'établissement d'une usine d'injection plastique dans le futur pour la production de certains composants en plastique importants, non seulement pour obtenir un avantage de coût mais aussi d'accroître le savoir-faire. Pour ce but, dans la deuxième partie de l'étude, le problème de la sélection de location d'emplacement vise à être résolu en appliquant les méthodes TOPSIS confus et des AHP floues et les résultats sont comparés les uns aux autres.
*Conception de mots clés : l'emplacement de layout; sélection de location de l'emplacement; CRAFT; fuzzy AHP, fuzzy TOPSIS.*

**ÖZET**

Tesis yeri seçimi ve tesis yeri tasarımı ile ilgili kararlar sadece üretim ve taşım maliyetlerini değil aynı zamanda üretkenlik ve tedarik zamanlarını da büyük ölçüde etkiledikleri için stratejik değere sahiptirler. Buna ek olarak, bu kararlar çok amaçlı karakterde oldukları ve süreçle ilgili olarak gerekli verilerin toplanması esnasında yaşanan problemler nedeniyle karmaşık yapıda görevler olarak tanımlanırlar. Buna bağlı olarak, bu iki problem her zaman endüstri mühendisliği literatüründe önemli bir yere sahip olmuştur. Bu çalışmanın amacı Türkiye'de Tekirdağ bölgesinde yer alan bir fabrikada tesis yeri seçimi ve tesis yeri tasarımı problemlerini sırasıyla çözmektir. İlgili firmanın, aynı tesis içerisinde altı farklı fabrikası yer almaktadır ve içlerinden birisi olan tüketici ürünleri fabrikası yeni kurulmuştur. Çalışmanın birinci kısmında excel tabanlı bir yazılım olan CRAFT kullanılarak, malzeme taşıma maliyetlerini düşürmek üzere yeni yerleşim tasarımları önerilmiştir. Çalışmanın bir parçası olarak, mevcut durum analiz edilmiş, gezi ve taşıma maliyeti şemaları ortaya konulmuş ve ilgili yazılım kullanılarak en iyi yerleşim ortaya konulmaya çalışılmıştır. Buna ek olarak, firma sadece maliyet avantajı kazanmak için değil aynı zamanda da teknik bilgisini artırmak için bazı önemli plastik parçaları üretmek üzere plastik enjeksiyon fabrikası kurmayı düşünmektedir. Bu amaçla, çalışmanın ikinci kısmında tesis yeri seçimi problemi bulanık TOPSIS ve bulanık AHP kullanılarak çözülmüş ve sonuçlar birbiriyle karşılaştırılmıştır.

*Anahtar Sözcükler: Tesis Yeri Tasarımı, tesis yeri seçimi, CRAFT, bulanık AHP, bulanık TOPSIS*

# 1. INTRODUCTION

Facility layout design or re-design problem is acknowledged as one of the most challenging and frequently repeating problems of many companies. A facility is defined as a unit in which any kind of job can be more easily conducted and it can be either a work center, a department, a warehouse or a machine tool etc. (Heragu, 1997). As explained by Taghavi and Murat, arranging the process elements required for production and delivery of services is inspected under the concept of facility layout design (2011). As further stated by the authors, related process elements can be either work centers, storage areas or a combination of machines. It has to be pointed out that facility layout design is a strategically important decision in nature since not only a series amount of money but also time and a well-defined planning is required to accomplish layout design procedure successfully. Moreover, a good layout design will increase operational efficiency since cost and performance of operations are highly affected with layout design decisions (Tompkins et al., 1996).

Rest of the decisions related with organizing the processes like making a selection between necessary technological alternatives are conducted following that layout design is completed. Following that all necessary data is collected, facility layout designer decides the configuration of machines or other process elements with respect to some design criteria in a way that selected objective will be actualized (Taghavi & Murat, 2011). As explained by Heragu & Kusiak, minimization of total material handling distance or cost is the most frequently preferred layout design objective (1988).

As pointed out by Pillai et al., to generate layouts two different types of approaches as qualitative and quantitative exists. Generally quantitative approaches aim to minimize material handling cost whereas qualitative approaches generate layouts on the basis of closeness ratings between departments (1988). They further pointed out that facility layout problem is frequently formulated as Quadratic Assignment Problem (QAP) which aims to assign m departments to m location so that material handling cost can be minimized. On the other hand, they further emphasized that QAP is considered as NP-complete in which optimization methods are not adequate to solve these problems feasibly in an average time when the number of process elements is more than 15. This is why heuristic procedures are suggested to good suboptimal solutions under these conditions (2011). On the other hand, receiving support from computer software to facilitate layout design procedure is getting more widespread in real life problems.

In this study excel add-in developed for facility layout design was applied to solve facility layout procedures. Two different algorithms of traditional CRAFT and optimum sequence method are provided with this add-in. As the location of some of the departments has to be fixed, traditional Craft is selected to generate new design alternatives. It has to be pointed out that both of the methodologies are heuristic procedures which do not necessarily find optimum solution. However it helps designer to see which departments have to be located closer to each other in order to decrease material handling cost as the objective function of this algorithm is only material handling cost. It can also be considered as one of the disadvantage of this add-in depending on the fact that facility layout design is a multi-objective process.

Data collection was the most difficult task to achieve as it is the same with other approaches suggested for layout design problem. To define root problem, first of all current situation including work force, product groups, processes, existing layout was analyzed and it has been seen that by switching some of the departments material handling distances therefore workforce and material handling costs can be decrease to a great extend which demonstrates the necessity of a new layout design clearly. As the second step, a detailed literature review is conducted to define design methodology. With respect to its easiness in real-life applications and flexibility that it provides to designer, traditional CRAFT algorithm presented by above mentioned excel add-in is selected to solve design problem. Necessary data was collected as possible and some assumptions were conducted to generate from-to and transport cost matrixes as the basic inputs of the program. Following that the best layout design was generated by CRAFT iteratively, new layouts were defined and re-drawn in a commercial CAD program.

To minimize costs and maximize the use of resources, facility layout selections also have great importance for manufacturing companies besides facility layout design decisions (Chu, 2002b). As stated by Jarboe (1986), many different criteria such as human resources, climate, proximity to markets, have to be taken in to account while selecting a location for a facility. These criteria can be classified in to two main classes of objective and subjective. Jarboe further indicated that, objective criteria such as cost of investment can be defined quantitatively in contradiction to subjective criteria that can be defined qualitatively.

As stated by Hwang & Yoon (1985), literature consists of many precision-based plant location methods. On the other hand, it has to be emphasized that linguistic terms are frequently used in the process of evaluating the suitability of a location on the basis of various subjective criteria (Zadeh, 1975). As pointed out by Kahraman et al., (2003), traditional methods like center of gravity or factor rating are not totally adequate while handling the vague nature of linguistic assessment. Therefore, fuzzy based methods are highly recommended to overcome the vagueness resulted from linguistically evaluation of various alternatives under various subjective criteria as stated by Chu (2002b). Fuzzy set theory can be used to solve ill-defined multiple-criteria decision making problems under the existence of fuzziness aroused from human judgment and inadequacy of available information. For this reason, in this study fuzzy TOPSIS and fuzzy AHP methods are proposed to solve facility location selection problem where all ratings of different alternatives under different subjective attributes and weights of all different criteria are demonstrated by fuzzy numbers. In the literature, there are not only studies that use fuzzy TOPSIS but also other multi-criteria decision making methods (Ertuğrul & Karakaşoğlu, 2006). The difference of this study from other studies is that, related methods will be applied to a real life problem and the results will be compared to each other. The details of proposed methodologies will be explained in details in the related section.

Rest of the paper is organized as follows. An elaborate literature review of facility layout design and facility location selection as well as proposed fuzzy TOPSIS and AHP methodologies will be presented during the sections 2 and 3. Traditional CRAFT methodology and required excel add-in to apply this method is introduced in section 4. Additionally, the process of data collection, application procedure of related add-in and results will also be presented in this section. Section 5 and 6 are dedicated to facility layout selection problem by applying fuzzy TOPSIS and AHP methodologies consecutively. And finally Section 7 concludes the paper. According to the results taken from CRAFT, two different layout designs were drawn by a CAD program. Proposed layouts and more can be found in appendix section.

## 2. FACILITY LAYOUT DESIGN PROBLEM

Facility layout problems are basically related with locating the facilities of a plant. FLP is a task with strategic importance since facility layout design affects manufacturing, transportation costs; work in process, lead times and productivity to a great extend (Drira et. al, 2007). As stated by Tompkins et al., as a result of a successful facility design process, up to 50 percent of total operating costs can be decreased whereas total performance of operations can be increased with the same percentage (1996). As indicated by Garey& Johnson in their study of the year 1979, layout problems are generally complex and treated as NP-hard. Therefore numerous researches can be found about FLP in the literature. To estimate the performance and the gain of suggested layouts, simulation studies are also provided (Aleisa& Lin, 2005).

As stated by Lin and Sharp (1999), layout design is a hard and tedious task to achieve successfully with respect to its multi-objective nature and additional processes of data collecting. Achieving to generate adequate solution methodologies for fulfilling the requirements of problems have always been the main objective of past and present studies. As stated by Yang and Kuo (2003), algorithmic approaches usually have the objective of minimizing material handling costs through the procedure of distance flow minimization. However the basis of procedural approaches is mainly the experiences of experts. As they further stated; not only procedural but also algorithmic design methodologies are inadequate to solve design problems in practice. Depending on this inadequacy of existing procedures to solve layout design problems, researchers always tend to generate new and integrated solution methodologies. For instance Yang and Kuo (2003), have developed an integrated methodology of AHP and DEA in their related research of the year. In their research, they implemented a computer supported layout design tool to simplify the generation process of layout alternatives and to gather quantitative performance data like material handling cost or shape ratio. Some other examples of integrated methodologies will be further mentioned in literature review section.

### 2.1. Definitions of Facility Layout Design

There are many but almost similar definitions of facility layout design. According to one of these definitions, facility layout design is a combination of machines, working stations, storage areas, materials and departments of an existing or a new designed facility which requires elaborate analysis to achieve efficient production. Layout decisions have a significant impact on how effective and responsive is the system to changes, how fast the goods can be produced and how rapid they can be transported between stations. Furthermore; a reduction in cycle times, work in progress, material handling times, the number of bottlenecks and idle times can only be achieved on condition that an effective layout can be designed (Sule, 1994).

Facility layout problem can also be described as determination of most suitable arrangement for a new process (Tam and Li, 1991). Facility layout problem cannot be evaluated as an independent design problem as it has links with product, process and material handling system designs. Their relationships with each other can be shown in below figure 2.1:

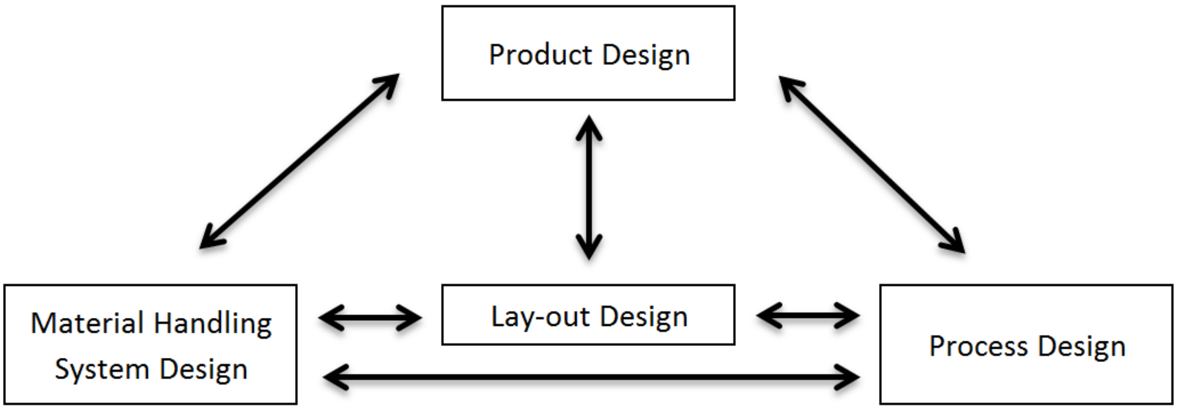


**Figure 2.1:** The relationship between Product, Process, Schedule and Layout Design (Francis and White, 1974, p.330).

With respect to a third definition, facility layout problem can be stated as figuring out the physical structure of an organization. For a manufacturing industry, facility location selection and determination of most efficient design are important issues concerning with the strategic planning perspective (Singh and Sharma, 2006). As stated by Tompkins and White (1984), approximately 8 % gross national product of USA has been dedicated to establish new facility design annually since 1955 in which it has to be emphasized that these numbers do not include restoration of existing facilities. On the other hand as Francis and White (1974), declared that material handling costs consist of 20 to 50 percent of all operating expenses in manufacturing. They further claimed that these costs can be deduced up to 30 percent annually by the help of an efficient facility planning. As a quantitative factor the most frequently used objective in mathematical models is material handling costs minimization. On the other hand, qualitative factors such as flexibility of layout for further changes, safety and aesthetics have to be also taken in to account (Singh and Sharma, 2006).

Heragu described the facility layout as placement of everything which is required to provide services or to manufacture products (1997). He further described a facility as a unit which assists to ease the performance of every kind of tasks like a department, a warehouse or a machine. Drira et al. explained that a common and definite description of layout problems do not exists with respect to different kinds of considerations found in the literature (2007). A great deal of researches which were so far studied in the literature is mostly related with static natured layout problems. Static layout problem was firstly studied by Koopman and Beckman in their related paper of the year 1957. According to their definition, facility layout problems can be considered as a general class of industrial problem in which the aim is to design a layout with the purpose of decreasing the cost of transport. In addition to the above explanation, Meller et al. took FLP in to account as a type of design problem in which the objective is to generate a non-overlapping planar orthogonal configuration of n rectangular facilities inside a rectangular arrangement area in order to decrease the distance based measure (1998). On the other hand, FLP is described by Azadivar and Wang (2000), as making necessary decisions on the location and allocation of a specific area to an expected number of facilities. As stated by Lee and Lee configuring n number of unequal sized facilities inside a definite total volume in a way that determining the borders of the length and the width of the given space with the purpose of material handling cost and slack area cost minimization (2002). Finally FLP is determined as an optimization problem in which the aim is to increase the efficiency of layout designs through the considerations of all available interactions between facilities and material handling systems by Shayan and Chittilappilly (2004).

### 2.2. Previous Studies in Facility Layout Problem

Layout problems are basically dealt with determining the location parameters of facilities like defining the places of machines or departments within the layout as previously stated. These problems have great importance for every kinds of organization since they influence the system performance to a great extent. There are a few published works of facility layout problems in the literature. Many of these problems are considered as NP Hard. There are also some literature reviews about FLP but many of them cover the problem to a broad range and are not capable of concentrating on a single aspect of the subject. On the other hand there are also some important examples of this kind like literature review research of Drira et al. (2007). It can be considered as a rather recent study which provides a general overview of layout problems rather than focusing on a specific aspect of the subject. As stated by the authors, their aim of preparing this research is not only to propose a general framework for readers while researching the literature about FLP but also exhibiting the current studies by utilizing the criterions as manufacturing system elements, static and dynamic aspects of the problem, problem formulation, discrete/ descriptions, solution approaches.

In a detailed literature research, it can be realized that facility layout design is a clearly active and emerging research area. Various papers in which all of them propose another kind of method have been published so far. Several new techniques can also make contributions to realize and develop different aspects of issue. Most recent trends in facility layout design problems are multi-objective approaches which will assist in developing facility layout software packages by utilizing meta-heuristic methods such as simulated annealing, genetic algorithm or concurrent engineering. All the approaches being considered to apply for solving design problems have to be elaborately examined within the concept of facility layout problems (Singh& Sharma, 2007).

Optimal facility layout design has to ensure communications among different departments of an organization which is the reason that the layout selection process is an iterative one. Facility layout selection is a difficult task which has to be undertaken by a creative and an experienced decision maker (Chakraborty & Banik, 2007). Thus, different methodologies, mathematical models and examples related with the facility layout selection can be found in the literature. For instance a methodology which takes various factors in to account was proposed by Harmonosky and Tothero (1992). Abdou and Dutta used an expert system and presented an integrated method for facility layout design (1990). In 1993 with the purpose of designing a layout, Raoot and Rakshit proposed a method which was based on the fuzzy linguistic variables and their relations. A method to solve multi criteria facility layout problem was developed by Shang in 1993. To decide which location should be joined to each other, an exact optimal solution for layout selection problem was introduced by Houshyar and White in 1993. In the year 1999, Dweiri developed an approach to form a crisp activity relationship chart by the help of fuzzy set theory and analytic hierarchy process.

To solve facility layout problems, a decision making approach was introduced by Yaman and Balibek (1999). To construct site level facilities layout Chau and Anson proposed a Knowledge-Based system in 2002. Yang and Kuo presented a method which was developed on the basis of AHP and data envelopment analysis as a solution of facility layout planning problem (2003). A fuzzy decision support system was improved by Deb and Bhattacharyya in 2005. Fuzzy Topsis was used for the purpose of facility layout selection by Yang and Hung in 2007. In the same year Chakraborty and Banik (2007), proposed an AHP based approach for the same problem. Kuo, Yang and

Huang applied grey relational analysis to deal with multi-attribute decision making processes with an example of a case study to select optimal facility layout (2008).

Maniya and Bhatt (2010) proposed a systematic and alternative multiple attribute decision making methodology for facility layout design selection problem. The basis of their proposed methodology is Preference selection index (PSI). According to this method, facility layout design is selected without taking the relative importance between facility layout design selections attributes in to account. In this article, two different types of facility layout design selection problems are demonstrated in order to control the accuracy; moreover a subjective cost benefit analysis is also conducted to define the benefits and the costs of related company.

In the literature there are also some reviews which attempted to present an overview of published researches. For example; in their related research of the year 2007, Singh & Sharma presented a review of different approaches for facility layout problems on the basis of supporting tools like formulations, solution approaches and software packages which are expected to be used for the purpose of overcoming difficulties in layout design problems. On the other hand, many literature review studies have also been conducted with the purpose of checking various dispositions and future research areas of FLP. However; as pointed out by Driara et al., (2007), some of these related researches could only concentrated on a particular feature of the subject as in the study of Asef et al. (2005) which is about loop layouts. The study of Balakrishnan & Cheng of the year 1998 which is about dynamic layout problems and the study of Pierreval et al., about design through evolutionary approaches (2003) can be considered as some other examples of literature review studies those focused on a specific aspect of the subject. As explained by Drira et al. (2007) although some of the researches which take place in the literature can still be considered as acceptable, some other issues have to be developed.

In addition to above mentioned studies, FLP literature consists of some studies that propose heuristic methodologies. For instance to solve an integrated problem of layout design and product flow assignment, an iterative heuristic procedure was proposed by Taghavi and Murat in 2011. As stated by the authors, the content of layout design decision part of the problem is that planar location of unequal-area machines with duplicates whereas product flow assignment part basically consists of assignment of machines in relation with product processing routes. As further pointed out by the authors the reason why they preferred to use a heuristic procedure is their thought about the inadequacy of classical approaches for large sized problems. This is why they applied an integrated heuristic procedure which is basically a combination of alternating heuristic, a sequential location heuristic and a perturbation algorithm. In their research they also provided an example to testify that the suggested method is effective to provide solutions not only for small but also for large-sized problems.

AHP which is a method developed by Saaty to solve complicated problems like multi-criteria decision making problems has also been widely used in the literature for FLP. The advantage of AHP is that it can be used as a supporting tool by decision makers for defining their order of preferences through a verbal scale (Yang & Kuo, 2002). As indicated by Finan and Hurley (1999), for supporting a single decision maker or a group of decision makers, related verbal scale can be used very efficiently.

Many different researches of facility layout problem can be found through a detailed analysis of literature. Facility layout is a multiple objective decision problem which can affect the performance of a service or manufacturing organization significantly. As stated by Yang and Kuo (2002) not only a procedural but also an algorithmic layout design approach is adequate to deal with the solution of a design problem practically. For the purpose of presenting a solution of FLP, they suggested an integrated methodology of AHP and DEA. In order to produce a set of layout alternatives and quantitative decision making unit outputs, they utilized a computer aided layout design tool. Multiple-objective layout problem was solved by DEA after the use of AHP to weight the qualitative performance measures. As of the many other studies with the intention of demonstrating the performance of their suggested methodology, a case study was also provided at the end of their related paper.

AHP was also used by Yang et al. (2000) for the purpose of assessing multiple-objective layout design alternatives. They developed related design alternatives on the basis of Muther's systematic layout planning methodology (1973) can also be found in their related research. As indicated by Yang and Kuo, AHP is a method that can manage to generate objective weights against a set of qualitative layout evaluation criterions however they further pointed out that it does not perform efficiently not only when a great number of alternatives exist but also when there is a need to select performance considerations. In their research Yang and Kuo presented an integrated approach of AHP and DEA. As stated by the authors AHP is developed to solve complex problems whereas DEA is significant to select boundaries of performance in various kinds of applications. They further pointed out that there are not many integrated approaches of AHP and DEA. One of these studies those attempt to integrate these two methods is the study of Sinuany-Stern et al. in which by integrating AHP, the concept of DEA analysis was broadened to total ranking from sole classification of efficient or inefficient. In addition, with the purpose of decision making unit determination Shang and Sueyoshi (1995) utilized an accounting process in which an AHP model was used to analyze nonmonetary criteria. As emphasized by Yang and Kuo, in the literature there are any studies which perform only DEA for facility layout design problems.

Foulds and Partovi (1998) used AHP in their research to determine a closeness relationship between planning departments of a layout problem in order to constitute a block plan which was basically generated depending on this closeness relationship. For the purpose of constructing a set of design alternatives different kinds of layout design methods were conducted by Cambron and Evans (1991) after which design alternatives are supposed to be assessed by AHP versus a set of design criteria.

There are also some studies those attempt to combine activity relationship charts with AHP to solve facility design problems. For example; Dweiri (1999) introduced an approach for developing crisp activity relationship charts which was basically structured upon AHP methodology and fuzzy set theory. As further indicated by Dweiri, the aim of integrating pair-wise comparison of AHP to this approach is to assure the consistency of designer decisions about importance of factors and the weight of each factor. As further indicated by the author, closeness ratings among departments are usually based on vague factors and usually represented by the help of conventional activity relationship charts. Some of the factors are more effective with respect to others about assigning the ratings.

## 2.3. Characteristics of Layout Problems

From the perspective of both service and manufacturing companies, layout design is a significant task to achieve related with its huge influence on future performance (Apple, 1997) and therefore it has been studied to a broad range (Meller and Gau, 1996). According to literature review results, algorithmic and procedural approaches are two main categories of layout design problems. With the purpose of attaining a substitute objective function, constraints of design as well as the objectives have to be simplified which are especially necessary to generate further solutions in later steps (Yang and Kuo, 2002). As stated by Heragu (1977), algorithmic approaches are the basis of many existing studies in the literature which can create efficient alternatives of layout particularly under the existence of computer aided tools like Lay OPT research of Bozer et al., which was conducted in 1994. It can be added that quantitative results of the algorithmic approaches are not adequate to provide every single objective of design. However qualitative as well as quantitative objectives of design procedure can be associated by procedural approaches as stated by Muther (1973). Related with these approaches, design process is separated into various steps which can be consecutively solved in later steps. For a successful application of procedural approach, an experienced designer usually creates quality design alternatives which are also the key elements of success. Therefore it must be added that as a result of the shortage of robust precise basis and objectivity such an approach may create an unsatisfactory solution which is a possible reason of hampering the application of a procedural approach for a layout design problem (Yang and Kuo, 2002).

Depending on the fact that layout problems are different from each other, these problems can be distinguished from other by taking their objectives and factors affecting layout designs in to account. Looking at the literature it can be said that a couple of goals are aimed to be achieved in facility layout design. As stated by Tompkins; minimizing material handling cost, production time and investment in equipment; providing a safe, comfortable and flexible environment for employees, simplifying the overall processes are some examples of the aims of facility layout design problem (1976). Depending on the relations of FL design problems with other design processes, to solve facility layout problems, the designer need to think and decide in a comprehensive manner. Especially it has to be stated that the relationship of facility layout design problem with material handling system design (Heragu and Kusiak, 1990) and production system (Abdou and Dutta, 1991) is really strong (Yaman & Balibek, 1999).

The most frequent studied factor in facility layout problems is material handling cost minimization. Beside, cost minimization as a quantitative objective, Francis et al. (1992) also studied qualitative objectives for FLP . The aim of decreasing material movement is not only for reducing work-in-process times but also to have more control on material by the help of establishing more standardized and simplistic processes (Fu & Kaku, 1997). As a result of achieving material handling cost minimization other objectives will realized concurrently. The aim of facility layout problems is determining the location of departments depending on their importance of proximity with each other. First of all the output of the solution is represented as a block layout. However an elaborate layout of different departments are later designated after deciding on the structure/size of the aisles, entry/exit points of materials which will affect the material flow route and the machine design problem (Singh & Sharma, 2006).

As stated by Drira et al. (2007) layout problems which have been so far studied in the literature were mostly related with particular characteristics of manufacturing systems. They explained that the essence of the problems typically distinguished by many factors and design concerns, for instance by production volume/diversification, material handling system applied, flow types for parts, number of floors that the machines will be assigned.

Drira et al. (2007) classified these factors according to their level of significance as follows:

* Products variety and volume
* Facility shapes and dimensions
* Material handling systems
* Multi-floor layout
* Backtracking and bypassing
* Pick-up and drop-off locations

### 2.3.1. Products Variety and Volume

Production volumes and variety of products usually affect layout design. As stated by Dilworth (1996), four types of organizations which are fixed product, process, product and cellular layout have been researched by many authors differently in the literature. In fixed product layout type, products are commonly distributed inside the manufacturing facilities and as an important specification of these types of layout types; it is different resources not the product that moves to conduct the operations on the product. Industries those manufacture large sized products like ships or aircrafts consist of typical examples of this layout type. In process layout type, the aim is to cumulate facilities those have resembling functions. A broad range of products are the sign of a process layout type. When production volumes are high and diversity of products low, generally product layout type has to be considered. In this type of layouts, facilities are usually arranged with respect to the sub-sequential order of the production processes (Drira et al., 2007).

In order to handle resembling parts, machines are bundled to cells in cellular layout type in which the cells are required to be located on ground of facility. As stated by Hamann & Vernadat, the problem turns to an intra-cell machine layout problem when the problem concerned with one of these cells. Defining the optimal layout of machines in each cell is the objective of these kinds of problems (Drira et al., 2007).

### 2.3.2. Facility Shapes and Dimensions

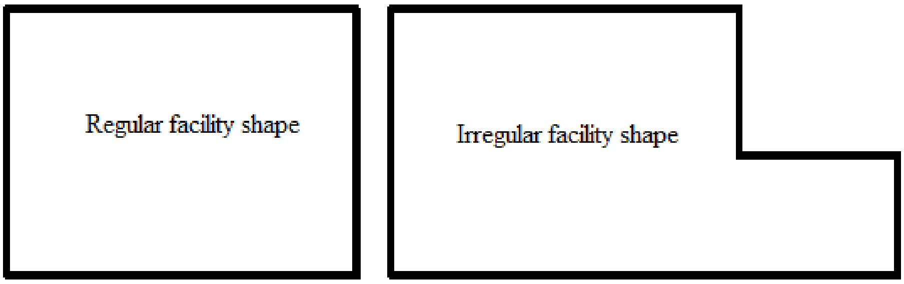


**Figure 2.2:** Regular and Irregular Facility Shapes (Drira et al., 2007 : 258).

Regular facility shape which is generally defined as a rectangular shape (Kim & Kim, 2000) and irregular facility shape which are typically polygons those include minimally an angle of 270 degree (Lee & Kim, 2000) are two basic shapes of facility layouts. Chwif et al. (1998), defined fixed or rigid blocks type facilities as a facility with fixed length of ($L_i$) and a fixed width of ($W_i$). The same authors also described a facility by its aspect ratio of $a_i = L_i/W_i$, in which the resulting equality can be shown as $a_{il} \leq a_i \leq a_{iu}$ when $a_{iu}$ is known as upper and ail is known as lower bound. Moreover they further claimed that fixed shape blocks can be described by the equality of $a_i = a_{il} = a_{iu}$. Aspect ratio was additionally mentioned by Meller et al (1999).

### 2.3.3. Material Handling Systems

Transporting materials from one place to desired locations are provided by material handling systems. As stated by El-Baz there are different kinds of equipment for material handling such as conveyors, robots, automated guided vehicles are some common examples (2004). As stated by Tompkins et al., handling of materials consists of 20-50 percent of the manufacturing costs and can be reduced up to 10-30 percent if the handling equipment is achieved to be arranged properly (1996).

Properly configuring facilities in accordance with the paths of material is the basis of material handling system design which is an important step of designing facilities. This is the reason why material handling selection and facility layout must be conducted dependently to each other (Drira et. al, 2007). As indicated by Heragu and Kusiak (1988), the model selected for determining the arrangement of machines are generally defined by the material handling equipment. In relation with the above statement, Co, Wu and Reisman also emphasized that selected handling equipment are also affected by the facility layout (1989). As it is considerably hard to solve both of the problems, Hassan proposed to solve them in a consecutive manner in his paper of the year 1994. Yang, Peters & Tu classified essential types of layouts on the basis of material handling as single row layout, multi-rows layout, loop layout and open field layout (2005).

Ficko et al. described the conditions for the occurrence of a single row layout problem as the obligation of locating facilities throughout a line (2004). Hassan emphasized the probability of considering various types of shapes those are derived from the initial basic setting as examples of straight line, semicircular or U-shape (1994). Potts & Whitehead described the loop layout problems as designating m facilities to location alternatives (m… l.) in a closed loop network surrounding which parts are shipped through one flow line (2001). In loop type layouts, there exists a Load/Unload (L/U) station which is necessary for the entrance and exiting of parts. The placement of this particular station is supposed to be between m and l. Hassan stated that multi-rows layout is concerned with facilities with several rows (1994). Additionally Ficko et al. pointed out that the movements of materials in this type of layout can be not only from the same row but also from the different row (2004). According to the description of Yang et al. (2005) open field layouts are occurred when there is no restriction of placement as a single row or a loop layout.

### 2.3.4. Multi-Floor Layout

As Drira et al. (2007) pointed out, transportation costs are usually high and supply chain is difficult to manage when a factory is built in rural area. A shortage in the utilizable horizontal space makes it necessary to use an additional vertical dimension of the layout in which the facility is located to several floors. In multi-floor layout type, materials can move not only through horizontal but also through vertical flow direction which is basically from one floor to another those located at different levels of a given layout. They further stated that, vertical transportation equipment like an elevator is necessary for ensuring the vertical transportation of materials. Related problems can be defined as multi-floor layout problems providing that not only their locations on the ground but also their levels have to be designed for each facility (Kochhar & Heragu, 1998).

Johnson with his paper of the year 1982 in which he aimed to determine approximate locations of facilities in a multiple-floor construction can be considered as the first researcher who studied multiple-floor layout problem. Succeeding Johnson’s paper, some researchers like Meller & Bozer (1996) studied multi-floor layout problem in which they mostly considered the movements of materials in vertical direction from one floor to another. As claimed by Lee, Roh & Jeong (2005) in most cases elevators are used as material handling equipments to ensure vertical transportation in which number/location parameters of elevators may be known or can be determined by the help of an optimization process (Matsuzzaki et al., 1999). In their related paper capacity of an elevator is treated as a constraint. Patsiatzis & Papageorgiou (2002) stated that areas of each floor, number and dimensions of facilities are the factors those have an impact on the number of floors when they are not definitely known.

### 2.4. Static vs. Dynamic Layout Problems

It has been further stated that in order to ensure flexibility, manufacturing plants have to adopt changes in production volumes, demands and variety of products. Additionally, it was also previously indicated that methods to design layouts are typically varied with the characteristics of facilities. In 1991, Page stated that new products consist of forty percent of company’s sales. However any related change on the product types has significant effects on layout and necessitates some modifications on production flow. As stated by Gupta and Seifoddini, in every two years 33% of USA companies experience a large-scale restructuring in production facilities. Related with its significance from the managerial side, various researchers have so far studied layout design problem. Many of the papers in the literature dealt with static type of problems in which they suppose that the basic data and the production figures will be fixed over a long time period. In addition to static layout problems, many researchers have also recently studied dynamic layout problems (Drira et. al, 2007). As indicated by Menget al. different from static layout problems possible changes in material handling flow over multiple periods are considered in dynamic layout problems (2004). From this point of view, planning horizon is generally divided in to defined periods which can be specified in weeks, months or years and it is supposed that flow data is fixed for each period. A number of layout plans each connected with a specific period are generated in dynamic layout problems. Baykasoğlu, Dereli & Sabuncu (2006) determined the objective of dynamic layout problems as defining a layout period for each period in planning time fence in such a way that the sum of the material handling costs are minimized in all periods whereas total reorganization costs are minimized between time periods. Additionally, as pointed out by Baykaşoğlu & Gindy (2001) when there is a need to relocate facilities from one place to another, rearrangement costs also have to be taken into account.

## 2.5. Facility Design Methodologies

Facility layout problem is one of the most challenging problems that many manufacturing and service organizations confront with. There is a broad range of facility design methodologies in literature. For instance, a Mixed Integer Programming (MIP) for FLP has been suggested by Montreuil which can also be considered as the starting point of various rounding heuristics (1990). Despite that, as pointed out by Meller et al. (1999) any supplementary studies have not been yet conducted to solve this related MIP in an optimal manner. They further stated that it is considerably hard to solve this problem even for the existence of less than five departments (n) even though related MIP consists of only 2n(n-1) binary variables. In their study Meller et al. (1999) worked on developing Montreuil's model through describing his binary variables again and tightening the constraints of departmental area. They suggested some conventional classes of available inequalities depending on the acyclic sub-graph structure that the related model based on. As stated by the authors, they partly managed to extend the range of problems that could be solved by the method through the way of applying related mentioned inequalities in a branch-and-bound algorithm. On the other hand they additionally emphasized that proposed method is not adequate to solve problems those have the size of a practical usage. Moreover it was also indicated that many other design problems such as circuit layout design also extensively used the disjunctive constraint structure which is also the basis of related FLP model and as a result of this fact a number of applications can get benefit of this study if polyhedral structure of this challenging class of MIP's can be explained more comprehensively.

There are a wide range of studies in facility layout design area. According to many of these researches; the solution methods of facility layout problems can be classified in to two groups as qualitative and quantitative methods (Francis and White, 1976). Additionally, layout problems may vary depending on the factors, problem formulations, objectives, constraints and also methodologies which are suggested to solve layout problems as explained by Drira et al., (2007). In related research, basic elements of FLP characteristics are provided in a tree representation for the purpose of simplifying the process of literature review.

In their related paper, Singh and Sharma (2006) stated that output of FLP is usually a block layout that is useful to define the location of each department which can be considered as a starting point for determination of a detailed layout of departments. In the following section basic design methodologies of FLP to create block layouts will be defined.

### 2.5.1. QAP Model (Graph Theoretic Approach)

QAP is firstly introduced by Koopmans and Beckman (1957) which is NP complete and extensively used to formulate FLP. In reality a large instance of problem cannot even be solved by a powerful computer. The objective of the model that is used to solve FLP can be time, cost, and travelling time or flow minimization. In order to solve large instances of FLP, various heuristic methods have been proposed so far (Drira et al., 2007). Although heuristic methods and linear integer formulations have been developed to solve QAP, they are limited to solve specific problems (Sarker & Yu, 1994). In his research, Lawler (1962) pointed out the equivalent of QAP problem with additional constraints to a linear assignment problem.

The below formulation of QAP model is cited from the study of Koopman and Beckman (1957).

$$\text{MinTF} = \frac{1}{2} * \sum_{\substack{i=1 \\ i \neq k}}^{n} \sum_{\substack{j=1 \\ j \neq l}}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} F_{ik} * D_{jl} * X_{ij} * X_{kl} \tag{2.1}$$

$$\sum_{j=1}^{n} X_{ij} = 1, \text{ for all i} = 1\ldots\text{n} \tag{2.2}$$

$$\sum_{j=1}^{n} X_{ij} = 1, \text{ for all j} = 1\ldots\text{n} \tag{2.3}$$

$X_{ij}$ = 1 if facility "i" is located /assigned to location "j".
$X_{ij}$ = 0 if facility "i" is not located / assigned to location "j".
$F_{ik}$ is the flow between two facilities i and k.
$D_{il}$ is the distance between two locations i and l.

The objective function of this model is to minimize total flow among the first to last facility as i = 1...n and k = 1…n. According to the first constraint, each facility should be assigned to a location and the second constraint makes it certain that each location can be matched with one facility. Depending on the fact that all indices are summed from 1 to n, each assignment is said to be counted two times and therefore has to be multiplied by ½ (Koopman & Beckman, 1957).

### 2.5.2. Graph Theory Model

In a graph theoretic approach, without taking the area and shape of the departments in to account, all departments are represented with a node within a graph network at the beginning (Hassan & Hogg, 1987). The importance of proximity for each facility is defined at first and the structure of the network depends on these definitions (Foulds, 1991). With another explanation of the model, in this approach, the assumption is that the importance of locating each facility is known. Similarly to QAP methods, problems of unequal size cannot be solved optimally (Meller & Gau, 1996). Different studies, each propose another approach and assist to observe new aspects of the problem have been published related with this problem so far.

### 2.5.3. MIP Model

MIP was first formulated as a FLP by Montreuil (1990) and his research is an important source of MIP for FLP. Even though there are big expectations from MIP for solving FLP, for today its capacity is only beneficial to solve smaller sized FLP'S. In this approach, flow time rectilinear distance between the centers of two departments is the basis of objective. At the beginning MIP approach was basically considered as an extension of discrete QAP where a distance based approach was used (Singh & Sharma, 2006). Heragu and Kusiak (1991) are the ones who improved a specific instance of MIP. A two-step algorithm was presented by Lacksonen (1994) to solve a dynamic facility layout with versatile departmental areas under the assumption of all these areas are all rectangular. In the further steps of the research this model was developed by Lacksonen (1997) in which the new model can handle with rearrangement costs and unequal areas. As stated by the author, disadvantage of this model is that it only presents optimal solutions for small sized problems. Moreover Kim et all. (1999) studied the problem of positioning input and output points of each and every department for a given layout under the objective function of total transport distance minimization. In addition to these developments, a branch-and-bound algorithm which apparently operates in an efficient manner even for large size problems was proposed recently. On the other hand the solution for the block problems and the input output point layouts has not been cleared out yet (Singh & Sharma, 2007). On the other hand, a mathematical modeling methodology for more common facilities layout problem has been introduced and represented by Barbosa et al. (2001).

### 2.6. Formulation of Layout Problems

With respect to problem characteristics and type of the problem as static or dynamic, layout problems can be solved by various methods. Different types of models which are essential to define complicated relationships existing among several features of layout problem are also based on the problem classification as dynamic or static (Drira et. al, 2007). Different theories like graph theory (Proth, 1992) or neural network (Tsuchiya, Bharitkar & Takefuji, 1996) are the basis of the related models in which they can be applied for the purpose of solving layout problems. Facility location problems are generally treated as optimization problems those may have single or multiple objectives. The most frequently debated facility location problems in the literature are Quadratic Assignment Problems (QAP) and Mixed Integer Programming in which this classification depends on whether the problem is formulated as discrete or . For both of the cases, some researchers proposed fuzzy methods depending on their idea of required data could not be known precisely (Drira et al., 2007).

#### 2.6.1. Discrete Formulation

The related optimization problem is occasionally considered as QAP when the layout is addressed as QAP. In this type of formulation, the plant is separated in to rectangular blocks with equal shape and area and in the further steps each block is matched with a facility as stated by Fruggiero, Lambiase & Negri (2006).

Moreover; Wang, Hu & Ku added that providing that the facilities have areas with different sizes, it is possible that they can cover different blocks (2005). As taken from Balakrishan, Cheng and Wong (2003), a typical formulation when the objective is minimizing total material handling cost while defining the location of facilities is as follows:

$$min \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=1}^{N} \sum_{l=1}^{N} f_{ik} d_{jl} X_{ij} X_{kl} \qquad (2.4)$$

$$\sum_{i=1}^{N} X_{ij} = 1, \ j = 1, \ldots, N \qquad (2.5)$$

$$\sum_{j=1}^{N} X_{ij} = 1, \ i = 1, \ldots, N \qquad (2.6)$$

Descriptions of variables in this formulation are as follows:

N: The number of facilities in the layout

$f_{ik}$: Flow cost from facility i to k

$d_{jl}$: Distance from location j to l

$x_{ij}$: Binary variable that depends on whether locating facility i at location j.

The objective function (2.4) is representative for sum of flow costs between each pair of facilities. The second equation is necessary to assure that only one facility will be assigned to each location whereas equation (2.6) make it certain that each facility is placed at only a location.

With the objective of minimizing the number of backtracks for materials in single rows, discrete formulations are proposed by some researchers like Braglia (1996). In addition to Braglia, discrete formulation is also preferred by Afentakis for designing a loop layout with the purpose of minimizing traffic congestion (1989). Two basic types of congestion measures in loop layout design are Min-Sum in which the aim is to minimize total congestion of all materials and Min-Max in which the aim is to minimize the maximum congestion within all of the materials (Cheng et al., 1996).

Dynamic layout problems usually require discrete formulation of layouts. As stated by Baykasoğlu and Gindy, the problems should involve facilities with equal size and ensure the related constraints of "each facility must be assigned to one location and each location must be assigned to one facility as it is further defined with equations (2.5) and (2.6) (2001). On the other hand as added by Baykasoğlu et al. budget constraints can also be included for restructuring of facilities in ground level (2006) however the attention has to be paid for not going beyond the determined budget. Lacksonen (1997) pointed out that to represent the definite locations of facilities in plant site, discrete formulations are not adequate to model specific constraints like pick-up and drop-off points, clearance between facilities and the orientation of facilities. He further added that it is more beneficial to apply representation under such conditions.

### 2.6.2. Formulation

In the literature there are many articles those represent the layout in continuous formulation and as stated by Das (1993) this representation is usually directed as Mixed Integer Programming (MIP). Das also indicated that, the condition to apply this formulation is that; all the departments can take place anywhere inside the plant site but overlapping of these dedicated locations is not allowed.

As stated by Chwif et al., (1998) the facilities in plant site are located either by centroid coordinates ($x_i$, $y_i$), half-length $l_i$, half width $w_i$ or by the coordinates of length $L_i$ and width $W_i$ of facility or by the coordinates of bottom-left corner. The distance between two facilities can be signified by many different forms for example through rectilinear form as shown in below equation taken from the research paper of Drira et al., (2007).

$$d_{ij}\left((x_i, y_i), (x_j, y_j)\right) = |x_i - x_j| + |y_i - y_j| \qquad (2.7)$$

Yang et al. proposed that constraints in concern with layout problem formulation can be created by pick-up and drop-off points (2005). Moreover, many researchers such as Kim and Kim (1999) studied on the specific problem of defining optimal locations of P/D stations. As an area constraint of plant site, sum of all facility areas have to be lower or equal to the total area available. Lacksonen (1997) stated that required area to operate the machinery have to be considered while defining the area dedicated to each machine. On the other hand as it was also emphasized by Heragu and Kusiak (1991), the clearance between facilities can be added or not to the surface of facility. Facilities should not overlap as another significant constraint, can be added to initial set of constraints. It has to be stated that during literature research, it was not encountered with many articles those were written about dynamic layout problems with formulation, however the study of Dunker et al. ( 2005) can be an example of this type in which they studied layout problems with unequal size in a dynamic environment and their assumption was that facility sizes differ from one period to another.

### 2.6.3. Fuzzy Formulation

Data required for solving layout problems are not definitely available in many cases. As stated by Meng et al. (2004) it is not so frequent to confront with stochastic methodologies like queuing models. Raoot & Rakshit (1991) added that in order to overcome the inexactness which is a rather frequent case, fuzzy logic can be applied. It has been confronted to some fuzzy logic based methodologies for facility layout design. For instance Evans et al. (1987) studied placement of unequal size facilities on plant site. In their related research, relations of every pair of facilities were defined by fuzzy variables as of closeness and importance. These relations provide necessary information to decision makers for the purpose of indicating significance with respect to each pair of facilities to be placed at any distance from each other. In their research of Evans et al. a fuzzy approach of the problem by using linguistic variables and a heuristic was suggested. In addition to Evans et al. (1987), Grobelny (1987) also dealt with the assignment problem of locating n facilities to n fixed locations under the objective function of minimizing total material costs. He indicated that the data like closeness links and traffic intensity those had observable effects on layout design were fuzzy and have to be formulated with linguistic variables by using fuzzy approaches.

With the objective of choosing and placing facilities to proper locations, a heuristic procedure under the basis of binary fuzzy relations was improved. Moreover, Raoot and Rakshit (1991) studied on a few principles of fuzzy approach in which they aim to define optimal layout configuration of facilities depending on their specifications among each other which are specified by linguistic variables. Additionally, a multi objective multi-row problem with unequal areas is called attention by Gen, Ida and Cheng (1995). They basically considered such cases that the clearance cannot be definitely expressed and therefore have to be treated as fuzzy. On the other hand, Dweiri and Meier (1996) have researches about discrete facility layout and in their researches they considered the quantity of materials transported between facilities, the amount of information flow and the number of material handling equipment as fuzzy factors. On the later steps of their proposed methodology, an activity relationship chart (ARC) which was based on the evaluation of experts was created with the purpose of defining the relations between each pair of facilities. As stated by Drira et al. (2007) ARC was later included to CORELAP which is a significant heuristic to find the best placement of facilities.

Aiello and Enea (2001) debated the identification of product market demands by fuzzy numbers depending on the fact that these data include ambiguity. In their related study, their objective was to minimize material handling costs inside a single-row layout design in such a manner that the condition of production capacity would be limited for every department had to be ensured. For the purpose of solving single row layout problem, fuzzy demands are broken down in to a-cuts and a-level fuzzy cost of each alternative layout is calculated. Additionally, with the same purpose of minimizing material handling costs, Deb and Bhattacharyya (2005) studied the subject of placing facilities with pick-up and drop off points in a continuous space. The personal flow, environmental and information relationships are some of the factors which were defined by the authors as the ones having an impact on the layout design. These factors are evaluated by using linguistic variables such as high, medium or low. On the basis of a set of fuzzy IF-THEN rules, the authors developed a decision support system in the later steps of their related methodology. Then in order to define the places of facilities in plant site, a construction heuristic is applied.

## 2.7. Multi-Objective Layout Problems

The main objective of many layout problems those were encountered in the literature review is related with minimizing a function which is mainly generated depending on the circulation of materials such as travel time, travel distance, material handling cost and etc. With the purpose of reflecting real time data to the model in a smoother manner, some of the authors considered more than one objective. For instance, the objective function of Dweiri and Meier (1996) consisted of minimizing not only material handling but also equipment and information flow costs concurrently. On the other hand, in some of the papers different objectives were integrated under one single objective either by developing a linear combination of different objectives (Chen & Sha, 2005) or by applying an analytic hierarchy process approaches (Yang & Kuo, 2005).

On the other hand, there also exist some researchers those tried to use the advantage of a Pareto methodology for creating a set of non-dominated solutions. Aiello, Enea and Galante (2006) studied on a layout problem in which they aimed to minimize material handling cost and contiguity function which can be defined as evaluation of adjacency between two different departments. In the later steps of the related research, the set of non-dominated solutions are generated and an optimal solution is later chosen among the set by applying a method of ELECTRE.

In the literature of layout design problem, it is really common to confront with problems in which other problems have to be simultaneously solved with FLP. Implementing a cellular manufacturing system in which the aim is both assignment of machines to cells and determination the placement of each machine inside the cell can be a clear example of the above explanation. The placement of every single cell in the layout also has to be specified in the related example (Singh & Sharma, 2007). Additionally these issues can also be directed as a single problem instead of proposing to solve them in a consecutive manner as stated by Gupta et al. (1996).

### 2.8. Decision Analysis Aspect of Facility Layout Design Problems

Optimal facility layout selection between various alternatives is a multi-attribute decision making problem as it depends on evaluating different criterions like material flow, information sharing, and integrity among different stations. It is such an extended problem that there exist different kinds of software and computer aided programs to select between facility layout alternatives. According to literature researches, for the purpose of evaluating and selecting optimal facility layout, multi attribute decision making methods are widely used. As in many multi attribute decision making processes, decision makers are supposed to estimate the weights of every selection criteria and assign a relative importance to them (Maniya & Bhatt, 2010).

Provided that the decision maker does not have enough experience about facility planning, there exist the possibilities of assigning unsuitable weights to facility layout design attributes which will lead to unsatisfied results like an increase in the total production costs or the misuse of available resources. Therefore facility layout design selection process should be done under the responsibility of competent experts who can solve the problem by making necessary calculations step by step through a methodological study. For the purpose of solving facility layout design problems, the designer must make decisions in many different areas. Decision analysis is an important step of design process not only because it will help designer to see opposing objectives but also this step will perform as an assisting tool (Maniya & Bhatt, 2010).

Many definitions of decision analysis can be found in the literature. For example in the study of Corner and Kirkwood, decision analysis is described as a collective of quantitative methods to examine decisions that use expected adequacy as principle with the purpose of selecting among different decision alternatives.

In the study of Yaman and Balibek (1999) it was stated that, facility layout problems can be distinguished depending on whether there exists a single or multiple decision makers those have to decide among different alternatives on the basis of one or more criterions. It is very clear that in order to present a satisfying solution for the problem the decision maker needs a well-defined process to follow. It is the task of decision analyst to structure decision making steps. According to the same study of Yaman and Balibek (1999), the main problem of decision analysis for facility layout design is defined as the unstructured nature of decisions. Because of the vagueness of unstructured decisions, the evaluation process is not easy and the alternatives are difficult to compare. The most devastating result of this situation is the lack of certain knowledge that should be provided decision maker in order to come to a precise solution. These kinds of unstructured decisions can be called non-programmed decisions (Holsapple and Whinston, 1992).

Analyzing the decisions during the overall process of facility layout design is really important. Moreover the existence of an experienced decision maker to reach a good solution is an important point of the process. Because of this reason, in order to help decision maker facility layout expert systems can be utilized. When the alternatives are almost unrestricted and the problem is to general, it is difficult to end up with a solution. Therefore numbers of alternatives are bounded to a limited size. Decision analysis and decision support systems are useful tools to decide facility layout problems (Yaman & Balibek, 1999).

### 2.9. An Overview of Decision Analysis Methods in Facility Layout Problems

There are various types of decision analysis methods in the literature. As indicated by Bunn (1984), the earliest forms of decision analysis studies started with decision tree approach which is a useful tool to exhibit vagueness and different steps in a decision problem. The central point of many decisions is exchanges between multiple objectives. As further stated by the authors, all the objectives, trade of decisions and risk disposition of decision maker is accumulated in a utility function in order to generate a numerical value related with each decision alternatives. This is an important method to follow as it will help to provide objectiveness.

Another approach of decision analysis is that the analytic hierarchy process which was firstly introduced by Saaty (1980). In the AHP method, the main goals of decision objectives are the elements of a hierarchy process. While using this method for decision analysis, the objectives are separated into more specific elements through the hierarchy. According to this method, decision alternatives take place at the bottom of the hierarchy and these alternatives are directly connected to upper elements of the hierarchy. Moreover; from top to the bottom decision alternatives are weighted (Yaman & Balibek, 1999). As stated by Lee (1972), goal programming is another frequently used approach in multiple criteria decision analysis in order to solve facility layout design problems. Outranking approaches related with the facility design problems consist of Electre and Promethee. Moreover as introduced by Zadeh (1970) the fuzzy set theory is a useful tool to solve multi-criteria decision making problems.
Methodology of decision analysis can be simplified as in the following figure:

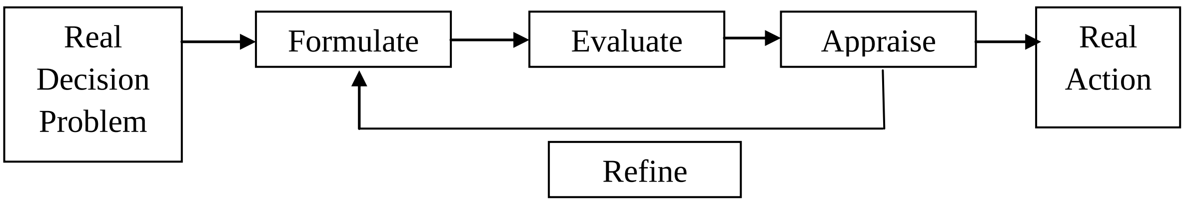


**Figure 2.3:** Decision Analysis process (Howard, 1988, p.182)

## 2.10. Facility Layout Solution Approaches and Their Decision Making Structures

Multi-criteria methods are regarded as the basis of many current approaches and algorithms. These approaches may try to verify two different adverse objectives like minimizing total cost and maximizing proximity concurrently (Yaman & Balibek, 1999). There are many studies in the literature those attempted to present a general scope of facility layout techniques as it is in the literature review study of Welgama and

Gibson (1995). In their research, they focused on analyzing a review of hybrid, multi criteria, fuzzy-set and artificial intelligence based algorithms.

This section of the literature research has been dedicated to introduce solution approaches to solve the problem of facility layout problem in an optimal or approximately optimal manner. Exact procedures, heuristics and meta-heuristics will be discussed under the concept of solution methodologies of FLP.

### 2.10.1. Decision Making Support Systems

Facility layout problems are basically unstructured decision problems. In order to solve the overall facility layout design problems there is a need to solve sub-decisions. As they can assist to gain time by providing objectivity, multi-criteria decision support systems are the assisting tools while making the main and the sub decisions. During facility layout design, fuzzy set theory can be applied to problem in some levels. A decision support system is a computer based support system in decision making process. These systems assist decision makers to focus on unstructured or partly structured decision. Expert systems are considered as a special kind of decision support system. The basis of these systems is rule management which is a knowledge based management technique (Yaman & Balibek, 1999).

### 2.10.2. Resolution Approaches

In the literature, it is possible to confront with various kinds of methodologies proposed for different type of layout problems. Most of the time the objective of this approaches can be either determining best solutions under such conditions that some specific constraints defined by the decision makers will be ensured or seeking a global or local optimum solutions to fulfill required performance objectives. This is the basic reason why there is a need for optimization based algorithms or heuristics. On the other hand there are also some papers those aimed to combine layout problems with artificial intelligence approaches (Drira et al., 2007). In addition to artificial intelligence, there are some researches those suggested to use expert systems like the paper of Heragu & Kusiak (1990) in which they applied expert system approach for intra-cell problems. One of the more recent expert system based on artificial neural networks research applied for facility layout design of manufacturing system is conducted by Chung (1999). There is also considerable number of optimization approaches suggested so far in the literature.

### 2.10.3. Exact Approaches

There are various number of articles considering exact methods such as the research of Kouvelis and Kim (1992) in which a branch and bound algorithm was proposed for solving unidirectional loop layout problem. On the other hand the same approach was also suggested by Meller et al. (1999), for generating a solution to the problem of defining the location of n rectangular facilities within the available space. In their paper, general classes of valid inequalities those were generated on the basis of acyclic sub-graph structure were used in a branch-and-bound algorithm for the purpose of extending the range of solvable problems. In addition to Meller et al. (1999), Kim and Kim (1999) studied the problem of finding P/D locations on fixed sized facilities for a determined layout in their related research paper. In this problem the objective is determined as minimizing the total distance of material flows between P/D points and a branch and bound algorithm was proposed by the authors to find optimal placement of P/D point for each facility. Moreover, to solve dynamic layout problem with equal size facilities a dynamic programming was suggested in 1986 by Rosenblatt. Nonetheless, this methodology was only present optimal solutions to small sized problems.

As stated by Singh and Sharma in their paper of the year 2006, branch and bound methods are performed in order to solve quadratic assignment formulated FLP depending on the fact that QAP consists of only binary variables. They further stated that only the problems up to a size of 16 have been optimally solved in the literature. However when the size of the problem get beyond 16, even a super powerful computer cannot manage to solve such a big sized problem.

### 2.10.4. Approximated Approaches

Various types of heuristics and meta-heuristics have been improved by many researchers because of the fact that exact approaches cannot represent optimal solutions when the problem size is large. First of the two basic types of approximated approaches is construction approaches in which the layout of the facility is conducted in a consecutive manner until the layout is accomplished. The second type is improvement approaches an initial solution is generated to begin with the solution and this solution is later developed by creating new solutions (Drira et al., 2007). As stated by Drira et al. (2007), examples of construction heuristics are CORELAP, ALDEP, COFAD and SHAPE whereas CRAFT, FRAT and DISCON are the examples of improvement methods. As further explained by Drira et al. (2007) one can also categorized existed meta-heuristic based approaches as global search (tabu search and simulated annealing) and evolutionary approaches (genetic and ant-colony algorithms). To present a solution for facility layout problem, Chiang and Kouvelis (1996) studied a tabu search algorithm which is constructed on a neighborhood based algorithm containing a long term memory, a dynamic tabu-list, diversification strategies and intensification criteria.

### 2.10.5. Heuristics

An important part of FLP literature consists of heuristics. Although there are many classes of heuristics in the literature, 2 essential classes of heuristics can be considered as construction and improvement types of heuristics. A solution is constructed from an initial point in construction type heuristics whereas a front solution is improved in improvement type. The basic and the earliest type of method for the solution of QAP is the construction type, however they cannot generate good results. On the other hand a feasible solution is the starting point of an improvement based method in which the aim is to increase the quality of the solution by interchanging single assignments (Singh & Sharma, 2007). For example a preferred improvement algorithm that uses pair-wise interchange is CRAFT (Armour & Buffa, 1963). It should be added that improvement type algorithms can be integrated to construction type algorithms (Singh & Sharma, 2006).

**Table 2.1:** List of Facility Layout Packages (Singh & Sharma, 2006)

| List of Facility Packages | | |
|---|---|---|
| **No** | **References** | **Name of Package** |
| 1 | Dr. Gordan Armour | CRAFT |
| 2 | Seehof and Evans | ALDEP |
| 3 | Dr.Moore James | CORELAP |
| 4 | Michael P. Deisenroth | PLANET |
| 5 | Teichholz Eric | COMP2 |
| 6 | Kaiman Lee | COMPROPLAN COMSBUL |
| 7 | Robert C. Lee | CORELAP8 |
| 8 | Robert Dhillon | DOMINO |
| 9 | Teichholz Eric | GRASP |
| 10 | Dr. Johnson T.E. | IMAGE |
| 11 | Dr. Warnecke | KONUVER |
| 12 | Dr. Warnecke | LAYADAPT |
| 13 | RaimoMatto | LAYOPT |
| 14 | John S. Gero | LAYOUT |
| 15 | Dr. Love R.F. | LOVE* |
| 16 | Dr. Warnecke | MUSTLAP2 |
| 17 | Dr. Vollman Thomas | OFFICE |
| 18 | McRoberts K. | PLAN |
| 19 | Anderson David | PREP |
| 20 | Moucka Jan | RG and RR |
| 21 | Dr. Ritzman L.P. | RITZMAN* |
| 22 | Dr. Warnecke | SISTLAPM |
| 23 | Prof. Spillers | SUMI |
| 24 | Hitchings G. | Terminal Sampling Procedure |
| 25 | Johnson (1982) | SPACECRAFT |
| 26 | Tompkins and Reed (1976) | COFAD |
| 27 | Hassan, Hogg and Smith (1987) | SHAPE |
| 28 | Banerjee et al. (1992) | QLAARP |
| 29 | Tam (1992) | LOGIC |
| 30 | Bozer, Meller and Erlebacher (1994) | MULTIPLE |
| 31 | Tate and Smith (1995) | FLEX-BAY |
| 32 | Foulds and Robinson (1978) | DA(Adjacency Based) |
| 33 | Montreuil, Ratliff and Goetschalckx (1987) | MATCH [Adjacency Based) |
| 34 | Goetschalckx (1992) | SPIRAL (Adjacency Based) |
| 35 | Balakrishnan et al. (2003) | FACOPT |

In Table 2.1 a number of heuristics based common layout software are presented. Two basic classes of these heuristics are adjacency and distance based in which it must be added that the difference between these two algorithms lies in the objective function. In adjacency based algorithms, looking at the objective function it can be noticed that material handling costs are dramatically lower provided that the departments are adjacent to each other. On the other hand, the logic behind the objective function of the distance based algorithms is that total cost of transport increases when the distance increases. CRAFT (Armour & Buffa, 1963) and FLEX-BAY (Tate & Smith, 1995) are distance based whereas MATCH (Montreuil et al, 1987) and SPIRAL (Goetschalckx, 1992) are examples of adjacency based algorithms (Singh & Sharma, 2006). These subjects will be later mentioned more elaborately in computer aided layout design section.

### 2.10.6. Meta-heuristics

To solve layout problem with facilities sizes of aspect ratio Chwif et al. (1998) suggested a simulated annealing algorithm whereas two simulated annealing methodologies to solve dynamic layout problem with equal size facilities was introduced by McKendall, Shang & Kuppusamy ( 2006). The first simulated annealing approach is basically a neighborhood based pair-wise exchange approach in which the placements of two facilities are randomly changed while the solution is simultaneously developed. On the other hand second simulated annealing approach is a combination of first simulated annealing algorithm and an improvement strategy (Drira et al., 2007). Genetic algorithms are also frequently considered to solve facility layout problems as stated by Pierreval et al. (2003). As pointed out by Driara et al. (2007) numerous articles have so far been published about this issue. Wang et al. (2005) for static and Dunker et al. (2005) for dynamic layout problems are the example of these papers. As stated by Drira et al. (2007) the basic problem of improving a genetic algorithm is to programming candidate floor plan.

As a meta-heuristic, ant colony optimization has also been suggested for layout problems. For instance, for a sequence dependent single row machine layout problem an ant algorithm was proposed by Solimanpur, Vrat and Shankar (2005). On the other hand, to solve unconstrained and budget constraint dynamic layout problems, an ant colony algorithm was introduced by Baykasoğlu et al. ( 2006). Additionally, there also exist some researches those integrated various met heuristics. With the purpose of minimizing material handling cost, a hybrid approach was suggested by Mahdi, Amet and Portman (1998) in which a simulated annealing algorithm is used to solve geometrical aspect of the problem whereas a genetic algorithm is proposed to design material handling system and to select an exact method to minimize total material handling utilization cost. In addition to Mahdi, Amet and Portman (2001) a hybrid approach for unequal sized facilities was presented by Mir and Imam. According to their approach, initial solution is generated by simulated annealing algorithm and an analytical search technique in a multi-stage optimization process is applied for determining the optimal locations of facilities. Another example of hybrid algorithm was presented by Lee and Lee (2002). In the related research they proposed a hybrid genetic algorithm for a fixed shape and unequal area facility layout problem. As stated by Drira et al. (2007), tabu-search and simulated annealing is initially used to determine local solutions and later a genetic algorithm was integrated in the middle of local search to acquire a global solution. A hybrid genetic algorithm which was previously studied by Rosenblatt (1986) was further developed by Balakrishan, Cheng, and Conway et al. (2003) to provide solution for dynamic layout problem. In their method, two methods are used for the generation of initial population which is a random method and a procedure of Urban (1993).

Simulated Annealing, genetic algorithm and ant colony are the most common meta-heuristics that are used to provide a solution for the large size facility location problems. Statistical mechanics theory is the initial point where simulated annealing give a rise and the basis of this technique is the correlation between finding a solution for optimization problems and the annealing of solid materials (Singh & Sharma, 2006). SA was established for QAP by Burkard and Rendl (1984).

Comparing to other meta-heuristics GA has recently taken more interest than other computation algorithms. A binary code for individuals is employed and it searches to find a local optimum that starts from a set of feasible solutions. On the next step new solutions are generated randomly in a parallel process. As the parameter settings and the framework of the problem are generally related with the characteristics of the problem, it can be stated that the overall performance of the problem is basically related with the nature of the problem (Singh & Sharma, 2006). Genetic algorithm usage for the solution of FL problem was examined by Tavakkoli - Moghaddam and Shanyan (1998). Another important meta-heuristics is that tabu-search algorithm which is designed as an iterative process for solving optimization problems. Tabu-search was first considered for the solution of FLP by Helm et al. (2000) but many researchers are still studying on this method and trying to improve it. In addition to tabu-search, there are also some attempts of applying ant colony algorithm for the solution of large sized FL problems like the paper of Talbi et al. (2001).

There are also some other approaches like expert system, fuzzy logic and neural network process are in use to solve FLP. For example; two dimensional neural networks were introduced by Tsuchiya et al. (1996) to solve FLP.

### 2.11. Computer-Aided Layout Design

As its influence on many fields has increased each day it is impossible not to consider computer to support layout planning and design problem which is one of the most essential topics of industrial engineering. In the literature many different mathematical models have been so far applied for the purpose of decreasing transportation costs and required area. It has to be also pointed out that what motivates researchers to consider new tools to facilitate the process of solving layout problems are the major difficulties to find necessary data and computational difficulties of related formulations. On the other hand models generated by computers are not adequate, solution techniques and other related algorithms also have to be applied to obtain a final solution. Algorithms are procedures which consist of principal number of steps and are performed to create a final solution in a stepwise manner. There are two basic types of computerized layout algorithms which are establishment and improvement algorithms (Türkmen, 2007).

### 2.11.1. Establishment Algorithms

Establishment algorithms generate layout design by starting an empty initial design. Program continues performing until all facilities are used in the layout. The steps of this algorithm are selecting initial layout and defining the facilities and the locations of related facilities those will be added to layout further. According to the study of Türkmen (2007) there are two basic types of computer aided layout planning methods which use establishment algorithms.

#### 2.11.1.1. CORELAP (Computerized Relationship Layout Planning)

CORELAP is an establishment layout algorithm that calculates total importance of closeness degree for all materials and makes layout design according to this degree. The first step of applying this method is to calculate the closeness importance degrees of departments by summing the closeness values (A=10000, E=1000, I=100, O=10, U=0, X=-10000). Department with the highest total closeness degree is located in the middle of the layout design. After this step, relationship chart is controlled and department which has an A relationship with first department is located close to the first selected department. If one or more department has the same closeness value than the one with the highest closeness importance degree is selected for locating closest to the first department. If there exists no A relationship, then designer has to make an analysis for E relationship whereas a search for I relationship is conducted if there is not an E relationship. Third department to be located is the one that has an A degree with the first two department that have been already placed. The procedure continues in the same way till the locations of all departments are defined. Relationship values have to be considered when deciding how to allocate departments to suitable locations. Degrees of location are equal to sum of the weighted closeness importance degree for a department with its neighbors (Ertay, 2010). CORELAP calculates the location degree by considering the value of location degree and the shortest path between departments.

#### 2.11.1.2. ALDEP (Automated Layout Design Program)

Under the existence of equality different from CORELAP, ALDEP assigns a department randomly instead of considering the closeness importance degree although they have the same data input and objective function. On the other hand; as a difference with CORELAP, ALDEP generates more than one layout plan and therefore the user may have the possibility to select between these alternatives (Türkmen, 2007).

### 2.11.2. Improvement Algorithms

Improvement algorithms aim to obtain final result by improving the initial solution that has been previously introduced to software. If the final result is better than initial solution, it is accepted and the improving process continues iteratively till there is no possibility to reach a better result (Türkmen, 2007).

#### 2.11.2.1. CRAFT (Computerized Relative Allocation of Facilities Technique)

CRAFT is a supporting tool in design problems that targets to minimize transport costs by altering the current layouts. In order to calculate transportation costs, this software uses material quantity that flows, distance and unit distance transport cost as input data. In such facilities that only one type of vehicle is in use, there exists also another possibility to accept number of flows as program input instead of quantity of materials that flows. Program looks for optimum design by iteratively changing layout designs and uses the areas of facility/departments, first layout plan, flow-cost data, and number of fixed and variable departments (Türkmen, 2007).

CRAFT determines the center of gravity point for each region in initial layout. It accepts distances between units as the distance between center of gravity points and transfers these data to a matrix called transport diagram. The aim of this program is to calculate total transport costs in unit time by considering unit distance transport cost matrix, flow matrix. Program calculates the transport costs for each unit change and stops when it achieves to get optimum layout with lowest transport cost (Türkmen, 2007). As the last layout is obtained by changing the initial design, it is possible to attain better results by running the program with first layout plan.

## 2.12. Different Applications of Facility Layout Problems

As previously indicated FLP is a type of combinatorial optimization problem which has been widely studied in different types of problems such as circuit board design, layout design of airports or hospitals, warehouses etc. However facility layout problems can also be extended to a broad range by generating different kinds of objective functions. For example some multiple attribute decision making studies those were developed to design an energy efficient facility layout design exist in the literature and these researchers have to be regarded as remarkable since they can provide an observable decrease in energy resources. In these kinds of studies the essential point is to combine energy dependent criteria with traditional criteria through layout planning process (Yang & Deuse, 2012). In their study of the year 2012, Yang and Deuse presented one of these solutions for energy efficient facility layout design problems. With the purpose of solving facility layout problems, related study of Yang and Deuse presented a methodology which was created by integrating AHP and PROMETHEE. As stated by the authors, AHP is required for defining the weights of each criterion whereas PROMETHEE is used for the purpose of attaining a final ranking. In order to verify the suggested method, they further provided a case study.

Conventional FLP methods generally take quantitative criteria such as material handling cost, space requirement etc. or some qualitative criteria like flexibility and quality in to account. However depending on the recent trends, factors like energy efficiency are also qualified as significant and has to be taken in to account in the early phases of layout designing (Yang & Deuse, 2011). Therefore these kinds of criteria have to be integrated with the traditional criteria during the facility layout planning procedure. Many FLP consists of various optimization objectives which are opposing in nature. Depending on this reason many multi-objective decision making methods have been generated those acquire a set of solutions instead of a single solution (Bhattacharya & Bandyopadhyay, 2010). Designers of the layout have to choose among the solution set which will best fulfill their practical requirements and preferences. It has been clearly stated by Jang and Deuse (2012) that layout decision making is a multiple-attribute decision making problem and related with multiple attribute features of these problems, assessing the alternatives of FLP is always difficult and a great deal of time is required to conduct this procedure . As they further indicated; there are inadequate numbers of researches about layout assessment even though developing an efficient facility layout is a rather crucial strategic decision. Depending on the results of an elaborate literature review it can be stated that with the purpose of generating various layout alternatives there exist several computer-aided layout design methodologies in which some of them perform AHP to assess these alternatives by taking a group of criteria in to account (Cambron & Evans, 1991). Jang and Deuse (2012) exhibited their reason of using AHP in their suggested approach as the capability of AHP to fulfill the weights for qualitative layout evaluation criteria whereas its inadequacy to differentiate quantitative criteria. They further emphasized that depending on the above reasons, there exist many studies that integrate other decision making methods with AHP. For example in his study, to solve facility layout design problem, Yang (2003) applied an integrated method of data envelopment analysis (DEA) and AHP as previously indicated. As well as the above mentioned studies, there are also some studies which are basically a combination of fuzzy AHP and TOPSIS those were developed to attain optimal results among various alternatives (Yang & Hung, 2007). On the other hand, grey relational analysis was also utilized for the purpose of solving multiple attribute layout decision making problems (Yang et al., 2008). As pointed out by Jang and Deuse (2012) same preference function was applied to get the results of assessment in all of the above mentioned methods.

In their research, Maniya & Bhatt (2010) proposed a framework that was based on Preference Selection Index method for the selection of optimal facility layout design.

The difference of this methodology from other multi attribute decision making processes is that there is no need to assign a relative importance among facility layout design attributes and also the weights of optimal facility layout design attributes are disregarded. Therefore the methodology is introduced by Maniya and Bhatt (2010) as easy to understand, user friendly, systematic and can be applied without too many computations. As further explained by the authors (2010), this method was firstly introduced for the purpose of material selection but further developed for layout design problems. They further explained the most important advantage of this method as no requirement to assign relative importance among attributes. On the other hand weights of attributes also do not need to be calculated which seems to decrease the computational complexity of this method.

## 3. FACILITY LOCATION SELECTION PROBLEM

The most common corporate growth strategies are mainly related with growing in global markets, like entrance to new markets or attempting start new businesses to get the benefit of economies of scale (Hoffman & Schniederjans, 1994). Many researchers emphasized the significance of facility location selection problem under the existence of unsteady and versatile environment of global economy (Badri et al., 1995). This kind of location problems that consist of global development are mostly connected with social, economic, legal, cultural factors and moreover they require considerable capital investment which will affect the limitation of manufacturing and logistics in long term. Like any other real-life problems, facility location problems are mostly complicated in nature and their dependence to other processes change from situation to situation. The basic reasons of difficulty to solve these problems are determining necessary considerations that will have further direct effect on selection procedure and fulfilling necessary adjustments between these considerations (Badri, 1998).

For manufacturing companies, selecting the most optimal location has gained significance since minimizing costs and maximizing the use of resources is one of the most important objectives to achieve. While selecting a location, there are several criteria to pay attention like human resources, climate conditions, availability of raw material etc. Depending on this reason, plant selection can be considered as a multiple criteria decision making problem (Liang & Wang, 1991). According to the literature review, facility location selection is a group decision making problem which is a non-repetitive process, requires the contribution of different departments of the organization and usually cleared up through a procedure that is not supported by a well-defined framework (Badri, 1998). Within the overall operation management, the methodology , the methodology of facility location is too broad including product/service design, planning of the capacity and facility layout design issues. Depending on the fact that decisions related with the design of the facility location influence each part of the organization, they cannot be made by only operational managers (Shen & Yu, 2009). Solely top managers can be responsible of these decisions or the company can also outsource necessary support to as well (Stevenson, 2005).

### 3.1. Content of Facility Location Selection Problems

Facility location selection problems are basically dealt with identifying the most suitable site for a firm for conducting operations. Not only locating but also relocating or expansion is considered as facility location decisions. Determination, examination, assessment and choosing between options are the steps of facility location decision processes (Yang & Lee, 1997). As they are long term, high-investment required and irreversible decisions, location selection problems have strategic importance. Moreover selected facility has an observable influence on costs and revenues. A careless location decision might be the most important reason of excessive transportation costs, lack of raw material or labor, loss of adequate logistics network or any other kind of problems those will badly affect operations (Stevenson, 1993). As indicated by Ertuğrul and Karakaşoğlu, typical steps of location decisions are as follows:

1. Identifying necessary criteria those can be used for evaluating facility locations.
2. Deciding on the crucial criteria.
3. Determining possible alternatives of location
4. Assessment and selection among alternatives (2008).

Although many criterions exist for facility site selection, some of them those may have a possible impact on decisions are more crucial. As an example of the possible facility location selection criterions, Ertuğrul and Nakkaşoğlu conducted their study in 2008 on five criteria which are: favorable labor climate, proximity to markets, community considerations, quality of life, proximity to suppliers and resources.

### 3.2. Significance of Facility Location Selection from Strategic Planning Side

Facility location selection has always been a crucial part of strategic planning decisions organizations. The overall location planning structure of facilities is determined as a result of numerous logistical decisions. Facility location or relocation projects are long term investments related with high costs of procurement and building new plants. Firms should ensure that the facility plans will be long lasting in order to benefit from more profitable enterprises. Therefore while trying to make facility plans the decision maker should not only select the location according to the current conditions but also he/she has to consider the future trends even environmental aspects, the possible changes of the market structure and the preferences of the labor. Due to the fact that decision maker should take in to account numerous future events, facility location selection can be regarded as challenging task to achieve (Owen &Daskin, 1998).

Companies which are aiming to achieve adapting regularly changing specifications of market conditions are confronted with several challenges depending on the global competition. Optimizing cycle times and inventory levels with the purpose of increasing customer satisfaction levels and ensuring to increase the competitiveness levels are some precautions taken by the supply chain team (Van der Zee & Van der Vorst, 2005). Besides, it should be emphasized that facility location is a significant process which has to be realized elaborately in order to increase the logistic performance of the overall facility which is necessary in order to optimize supply chain network (Coyle, Bardi & Langley, 2003). As a result of the global competition, market necessities are changing so rapidly which makes it quite difficult for many companies to follow and respond these developments. In such challenging conditions, possessing an efficient supply chain management is said to be the basic rule of being a fast-respondent organization (Ou & Chou, 2009).

Facility location decisions are regarded as an important part of strategic planning not only for governmental but also for nonpublic firms. There are many different aspects to consider while solving facility location selection problems which are basically related with the type of selection decisions. For instance either establishing a new factory or selecting a location for a new warehouse, decision maker has to always confront with obligation to decide about resource allocation. On condition that market and environmental changes occur, the need for a new facility planning approach gives rise, because large amount of investment has to be dedicated to complete this process. It is so clear that acquiring or constituting a new facility is a time and money consuming process which makes it obligatory to work elaborately before completing decision making process in many different fields like whether acquiring or constructing a new building. Therefore facility location selection problems require long term investments related with the high costs of these kinds of projects. In addition, the expectation of facility designers is that the facility keeps going on working for a long period. On the other hand, an optimal location for today's working conditions can turn into a catastrophic decision when the market and the environmental conditions change suddenly which makes it even more difficult to select best locations for new establishing facilities (Owen & Daskin, 1998).

Facility location selection can be considered not only as a decision making problem at the strategic management level but also a partly constructed process of supply chain management. Looking at the existing methods being developed to solve FLS problem, it can be realized that they mostly neglect their suitability of the strategy of the related firm and the basis of responsibilities of managerial level. In the study of Shen and Yu (2009), an empirical fuzzy approach was proposed which includes not only a process of risk assessment but also the managerial authorizations of responsibilities in administrative level under group decision making. The authors represent a numerical example for better understanding of the methodology and also to prove the efficiency of it. Additionally, as also stated by Shen and Yu (2009), their article is important for utilizing dynamic product-process change matrix as a guide to provide the true criterion related with the necessities of operational planning for facility location selection problem.

### 3.3. Literature Review

Due to the significance and complexity of facility location selection problems many different approaches have been proposed so far in the literature. In this section some of these studies those are not fuzzy set theory based will be introduced to provide a basic overview of location selection problems and possible solution methodologies. In the following section, methodologies those were developed on the basis of fuzzy set theory will be presented to show why applying fuzzy set theory to facility location selection problem may provide better results.

In the literature review it can be seen that there are numerous researches about the facility location selection decisions but the problem with these researches is that many of them are limited to static and deterministic models. On the other hand; in the past years there are also a few studies which attempted to analyze the stochastic and dynamic nature of facility location selection problems many of these studies have been published recently (Owen & Daskin, 1998). There are also some literature review studies that attempt to exhibit a general overview of facility planning. For example Owen and Daskin (1998) published an overview of strategic facility planning. In the related research, the authors intended to report the strategic nature of facility location problem regardless of distinguishing the characteristics of problem as stochastic or dynamic.

According to the literature research it can be seen that there are many studies for site location in which many of this effort has been dedicated to optimize the problem (Brown & Gibson, 1972). Moreover many studies in this field have dealt with the problems those have multiple objectives and as a result of these studies a wide range of methodology for the analysis of the problem have been proposed. For instance in his research, Geoffrion (1978) proposed an approach to analyze location problems which combines decomposition, simulation, heuristics and mixed integer linear programming. He also stated that a methodology which is developed to simplify managerial decision making procedure for location selection have to provide optimal result, perform efficient when computing and ensure advance analyzing for future period. The significance of the multiple criteria for further analysis has been emphasized by many researchers like Lee (1972) and Tuckman & Holmblad (1975). Among various formulations of facility location-allocation, the clearest is that the fundamental transportation/assignment, and linear programming formulation (Badri, 1998).

One of the most popular methods of solving facility location allocation problem is Analytic Hierarchy Process (AHP) which was first presented by Saaty (1980). By the help of AHP, the decision maker can simplify a complicated problem by generating a basic hierarchical structure for the purpose of assessing many determinants simultaneously in a systematic manner (Badri, 1998). Depending on the results of the literature research, it can be stated that to make a final decision, not only AHP can be used solely but it can also be used with a combination of other mathematical programming methods (Haghani, 1991). AHP is a method that contributes to generate an ideal ranking of alternatives but it does not take in to account the restrictions of existing environment. In case that the decision maker aims to achieve making allocation decisions concurrently, the problem turns into a more complicated form. When the problem is executed for an international environment, many real life restrictions like air quality, distribution costs have to be taken into account as they have the possibility of changing the results of selection process (Dyer, Forman & Mustafa, 1992).

In his paper, Badri (1998) stated that to solve facility location-allocation problems in a global environment, decision maker has to consider many factors at the same time, yet some of these factors may be opposing. To overcome the unstable and the complicated nature of the objectives in location allocation problems he offered to use a method that combines Analytic Hierarchy Process and Multi-objective goal programming. He further stated that his methodology may assist decision makers to specify location plans in an international environment. He offered to use two different methodologies for location selection problem. He only applied AHP in the first methodology to create additional criteria and after that he combined AHP and goal programming in the second methodology.

Also many other different approaches to solve facility location selection problem were developed so far. For instance Pine (1993) developed a product-process change matrix that included two broad categories of change as product and process change. This matrix is a useful tool for managers to position their companies in the competitive environment by assisting them to evaluate their past current and future situations as stated by the authors. In their study Shen and Yu (2009) broadened the aim of performing this matrix to address the assistive tasks of facility location and to define the criteria and the weights in order to estimate which location alternatives are most suitable to satisfy the requirements of the firm.

An extensive variety of objectives can be provided if multifactor rating system (FRS) is analyzed which makes this method a more extensively preferred one. In FSR method, with the purpose of getting total scores of individual alternatives, simple additive weight method (SAW) is applied which is regarded as a useful assistant to rank orders by preference (Heizer & Render, 2004). As explained by Liang and Wang (1991), even though traditional FSR approaches are widely used to solve facility location selection problems depending on their simplicity, they cannot handle ambiguity of decision making processes resulted from the existence of linguistic variables.

### 3.4. A Review of Static and Deterministic Facility Location Research

Location theory officially began with Alfred Weber (1929) who studied the problem of locating a single warehouse in such a way that the objective of minimizing the total distance among the customers and the warehouse had to be realized. After this first attempt to study of location theory, many researchers have further continued applying it for a variety of cases. The concern for location theory has been brushed up after the research of Hakimi (1964) which was a paper that basically dealt with locating switching centers in a network and police stations on a highway. In order to achieve the optimal solution, objective of Hakimi's study (1964) was to ensure the minimum total distance from customers to the closest facility.

The number of researches in location theory area has increased from the beginning of 60's. The most simple facility location problems can be formulized both as static and deterministic. In these kinds of problems, known quantities are taken as inputs and a single solution is created and implemented at one point. One of many possible criterions which are chosen by decision maker determines the solutions (Owen & Daskin, 1998). Moreover many of the researchers who are extensively studied on applied problems and inconvenient facilities have so far analyzed multi-objective forms of these simplest models (Current, Min & Schilling, 1990).

### 3.4.1. Dynamic Location Problems

Many of the papers published in the field of location theory have been derived from the application and the broadening of the simplest models. According to the literature review it has to be clearly identified that many of these models are excessively hard to solve. This must be the basic reason why many or the researches of the location theory have been dedicated to static and deterministic problem formulations. On the other hand different from the suitability of these formulations as a research topic, they are not functional to demonstrate the different perspectives of the real life location problems. Each and every acceptable model should take in to consideration ambiguity of the future in some point of views depending on the strategic character of the facility location problems. As the required capital to locate or relocate facilities is generally high, it is aimed that these facilities have to perform for a long period of time. Therefore it should be noted that the facility location problem should be considered for a long planning time fence. Facility location planner should not only responsible for defining the optimal location alternatives but also foreseeing the demand changing over time and also determining the expectation possibilities over time. The uncertainties been hidden in location problems can be analyzed under two main groups as the ones which are raised from the planning for future with ambiguity and the ones which are originated from the restricted knowledge of current model input parameters (Owen & Daskin, 1998).

### 3.4.2. Stochastic Location Problems

The aim of the dynamic models are to position facilities optimally or near optimally in a fixed time fence. Although they are more successful than static and deterministic formulations to demonstrate the complicatedness of the real life problems, the basic assumption of these models is that the input parameters are known or they diversify deterministically over the time. According to literature review there are two basic classes of research on location problems as probabilistic and scenario planning approach. System parameters such as travel times, demand quantities are considered as uncertain in both of the cases. The aim of these problems is to define optimal facility locations that will operate well after several parameter actualizations with respect to identified criterions. Scenario planning approaches take in to consideration possible future variable values while probabilistic models clearly consider the probability distributions of the modeled random variables (Mulvey, Vanderbei & Zenios, 1995).

## 3.5. Methodologies to Solve Facility Location Selection Problems

A broad range of researches have attempted to develop some methodologies to overcome the difficulties of facility location problem. Several mathematical models have also been generated in order to demonstrate different aspects of these problems and various objective functions have been used to ensure these models will be eligible to use in many different situations. But as a fact that many problems in this area are considered as NP-hard, it is seriously challenging to solve these models in an optimal manner. Furthermore there is a need for integer programming formulations to solve many of these problems. Looking at the literature, it can be realized that depending on the computational obstacles of the complicated facility location formulations, an important number of researches have been restricted to deterministic and static problems. As a distinctive property of these problems, all inputs like demand and distances are assumed to be known while the outputs are considered as single occurrence decision values. These kinds of problems are beneficial because of the fact that they can assist the location designers to possess a general point of view for the location selection. On the other hand it is so obvious that these problems are so far from modeling the uncertainties of the real life problems (Owen & Daskin, 1998). As stated by Averbakh and Berman, sensitivity analysis researches in this area is mostly related with the problem of input data ambiguity (1997). It can be stated that many studies that focus on the sensitivity analysis issue of location problems mostly aimed to calculate the effects of a change in parameter values on the optimal objective function value as Labbe et al. (1991). These results cannot help to integrate ambiguity in to the models although they are beneficial to assess the quality of solution.

One can find many approaches to solve facility location problems in the literature. Some of them are:

A hybrid Taguchi-immune approach is presented by Agrawal et al. (2010) in order to optimize an integrated supply chain design problem with multiple shipping. For the location of logistics distribution centers a bi-level programming model is proposed by Sun et al. (2008) and also some researches related with the multi criteria facility location models can be found in the literature. location models, integer programming models and location models can be considered as the most commonly used approaches. Every point on the plane is a possible candidate of facility location and in order to decide among locations a proper distance metric is used in location models. On the other hand, distances are computed as shortest paths and nodes represent demand points in network location models with the purpose of determining best locations for facilities (Awasthi et al., 2011).

For location selection procedure, there are many precision-based methods. Moreover in order to define best location alternative for facilities, researchers try to get benefit of mathematical programming tools as in the examples of Aikens (1985), Dahlberg & May (1980), Hodder & Dinçer (1986). For the purpose of assigning weights to subjective factors by realizing all possible pair-wise comparisons between factors, a method that is based on the preference theory was proposed by Tompkins and White (1984). On the other hand, in order to select an optimal facility location among various alternatives, a weight factor analysis method was suggested by Spohrer and Kmak (1984) to combine qualitative rating and quantitative data. Cost volume analysis method was introduced by Stevenson (1993) for plant selection problem. In addition to these studies, with the purpose of overcoming the problem of ranking and decision making with multiple criteria, many researchers have studied multiple criteria decision making methods (Hwang & Yoon, 1981). It has to be added that all the above mentioned methods assume that measured values are numerical and have to be evaluated as crisp numbers (Chen, 1998).

On the other hand not only stochastic programming but also scenarios planning methodologies are away from analyzing the sensitivity of solutions which can illustrate the ambiguity and complicatedness of the real life problems. Likewise, extended horizon models which are capable of temporal perspective of real life problems can be converted to instant models of one time decisions by dynamic modeling (Owen & Daskin, 1998).

Many researchers implemented integer and mixed integer formulations to solve facility location problems. For instance nonlinear programming was applied to location problems by Wolfe and Baumol (1958) in which the objective function of their study was to minimize delivery costs. Moreover some other researchers took the advantage of stochastic programming by justifying such distributions as demand and/or supply (Harrison, 1979). Other approaches that have been used for the solution of facility location problems consist of dynamic programming, multivariate statistics and heuristic methods (Kuehn & Hamburger, 1963). Depending on the literature review it can be said that there are also many facility location-allocation problems in which minimizing the costs is not the most significant objective (Badri, 1998). Geoffrion (1978) studied the field of multiple criteria goal programming comprehensively. On the other hand, AHP and TOPSIS methods depending on their easiness to adapt facility location selection problems have been widely used in this field which will be later more elaborately considered.

Fuzzy TOPSIS method is not only applied to facility location selection but also distribution centre selection problems as well. To make a proper location planning in order to minimize distribution costs and traffic problem which is resulted from goods moving from one place to another is really important. In the article of Awasthi et al. (2007) a multi-criteria decision making method under ambiguity is proposed for urban distribution centers. The represented method consists of determination of location alternatives, applying fuzzy theory with the purpose of weighting criterions and applying fuzzy TOPSIS to choose the best location for a distribution center. Furthermore sensitivity analysis is conducted to identify the effects of the weights on location planning decisions and a numerical application is also provided.

Assessment of different region, sub region and community alternatives are mostly named as macro analysis whereas assessment of a particular region within the selected community is named as microanalysis. Factor rating systems, center of gravity, analytic Delphi and linear programming are the methods those are applied for the purpose of macro analysis (Chase & Aquilano, 1995). As stated by Kahraman et al. (2003) heuristics, non-linear programming, multi-objective goal programming, multi-attribute utility model, multiple-regression analysis, analytic hierarchy process, analog approach are some of the traditional methods which are used for solving location selection. It has to be added that the problem with these approaches is that relationships between decisions factors are not taken in to account while a systematic methodology is supplied for problem solving. On the other as emphasized by the authors, the final outcome is substantially affected by the competencies and the experiences of decision makers. Moreover in addition to the above methods, artificial neural networks, fuzzy set theory and artificial intelligence methods are frequently made use to solve location selection problems. They further pointed out the promising applications of ANN's those have been conducted in the field of decision making.

For example by the help of using golden descent technique with the purpose of multiple criteria decision making, a feed forward neural network was introduced by Wang and Malakooti (1992). The efficiency of ANN methods as classifiers in the field of facility location were checked against each other by Benjamin et al. (1995). A database management system, a linear additive multi-attribute utility method, a graphical support and an expert system were integrated by Jungthirapanich (1992) to exhibit a decision support system. As stated by the author, the purpose of using data base management systems is that they can collect the data of location those are acquired from related documents. On the other hand to produce a suitability index for each location, he approved to get benefit of multi attribute utility method whereas with the purpose of defining the best locations and expressing their pros and cons, expert system was utilized in the same study of Jungthirapanich (1992).

### 3.6. Significant Factors for Facility Location Selection

Looking at the significance of facility location selection decisions, current situation and possible future trends have to be elaborately examined by decision-maker to determine all possible aspects before location selection process begins. Therefore it is so obvious that many factors have to be considered during the selection procedure. As stated by Badri (1998), to solve facility location allocation problems decision maker has to consider many factors at the same time, yet some of these factors may be opposing, especially in a global environment.

Many different types and aspects of facility location-allocation problem have been extensively studied so far. It has been realized that numerous applications and factors can be considered as significant for location-allocation problems. Some of these factors are: easiness of transportation, transportation costs, and availability of labor/raw material, market conditions, taxing issues, environmental aspects and evaluation of the risk factors. In addition to quantitative factors, qualitative factors are also important but the general approach related with the qualitative factors is addressing these factors to the responsibility of managers instead of paying attention to model and quantify them (Pietlock, 1992).

As explained in the article of Chen, the first step of location selection is to define the set of relevant factors such as labor force, proximity to raw material, transportation conditions and etc (1998). These factors can be examined under two broad categories as objective and subjective factors.

Choosing the best location between many alternatives when there are more than two factors is a multi-criteria decision making problem. It is rarely the case that the accurate values of qualitative criterions are assigned. Usually linguistic terms such as low, medium and high are used in order to describe importance weight of criteria. Therefore it has been stated by many authors that quantifying the rating of each alternative definitely is not possible when dealing with location selection problem. The fuzziness inherent in the nature of location selection problems are the motivating power of many researchers to study on fuzzy decision making methods (Chen, 1998).

### 3.7. Decision Making Aspect of Facility Location Selection

According to classic decision making theory, in order to analyze location alternatives, managers would first determine related criteria which are necessary to evaluate a series of options. From the managerial side, the next step is assigning importance weights of defined criteria. Then, all necessary information related with the possible location performance is collected (Kahraman et. al., 2003). As stated by Harrell & Kiefer (1981) one or more criteria are chosen to apply for the purpose of attaining optimal results. On the other hand Dubrin (2002) indicated that most of the criterions, weights and the rules of decisions are assessed by human perceptions which are impossible to express exactly with numerical values. This is also a natural result of ambiguity typically involved in location selection processes which is resulted from linguistic evaluation and multiple attribute decision making in these problems (Ou & Chou, 2009).

A series of alternatives with respect to particular attributes are evaluated in MADM. Looking at real life problems, it should be noted that the significance of each decision maker for a decision making attribute may not be uniform or may not have equal importance. Usually there exist more experienced experts in decision groups related with specific subjects. It has to be added that the final decisions are remarkably affected by these experts. A good way to cumulate different influences on a decision making process is to take evaluations of various decision makers in to account (Ou & Chou, 2009). In the study of Ou and Chou (2009), a fuzzy weight assessment approach was proposed for individual decision makers that can also be used for multiple expert opinions.

Set of alternatives in the case of selecting probable alternatives of location are generally determined by top managers in connection with their business environment, published reports, individual processes and etc. Information which is necessary to select facility location is provided externally and based on the human judgments. It is a non-repetitive decision and therefore has to be examined from many aspects. The authors further explained that depending on these issues to solve such kind of assessment problems, crisp values are never satisfactory. In the real life application of group decision making procedure, there usually exists a specific group of more experienced people or experts within the group. It can be said that the quality of the decision is utterly related with the number of these people. Depending on this fact it is well known that, in multi criteria decision making problems such as FLS, a beneficial way to reach better outcomes is to combine several kinds of individual ideas (Shen & Yu, 2009).

Depending on the literature review results, it can be clearly expressed that to propose reasonable solutions for location problems, fuzzy set theory and related techniques have been so far studied in a broad range (Ou & Chou, 2009). For instance; to solve location selection problems under fuzzy environments, a MADM method which is based on gradual ranking procedure was presented by Chen (2001). Moreover, to determine best location alternative, a fuzzy MADM methods which has the basic concept of ideal and anti-ideal point was proposed by Liang (1999). In addition to the related study of

Liang, as combining fuzzy set theory and analytical hierarchy process, Kuo Chi and Kao (1999) developed a decision support system for site selection problem.

An alternative fuzzy MADM method which has the basic concept of ideal and anti-ideal point was proposed by Liang (1991). In addition to the related study of Liang, as combining fuzzy set theory and analytical hierarchy process, Kuo Chi and Kao (1999) developed a decision support system for site selection problem.

As stated by Awasthi et al. (2011), the basics steps of their proposed methodology which are also the steps of a multiple-criteria decision making problem are as follows:

1. Selection of location criteria: To evaluate potential locations;
*Cost Type Criterion;* the lower the value, the more preferable the alternative for the best location. *Benefit Type Criterion;* the higher the value, the more preferable the alternative for the best location.

2. Selection of potential locations: To identify possible candidate locations for implementing urban distribution centers. Possible candidate locations have to own some properties. Actually the potential locations are the ones which own all the properties to supply all the interests of the possible stakeholders.

3. Evaluation of locations by using Fuzzy Topsis: There exist two basic differences for the cases of single and multiple decision makers. First of all the goals of individual decision makers may vary depending on the alternatives and second with respect to their decisions individual decision makers may require different kinds of data. N-person game theories, group decision theories, team theories for decision making try to cope with these differences when the case is group decision making (Kahraman et. al., 2003).

By using a fuzzy synthetic method Kuo and Chen (2004) conducted a study to assess and choose mobile value-added services. As stated by Ou and Chou (2009), a great deal of the existing studies like the AHP based ones can be regarded as quite complex depending on their computational difficulties. Although there is no need to consider it as a crucial problem depending on the recent developments in computing world, it may be an important problem if this computational complexity prevents managers from using fuzzy MADM methods (Ölçer & Odabaşı, 2005).

A rather new approach for group decision making was proposed by Kacprzyk et al. (1993) when linguistic variables are frequently used to express fuzzy majority and fuzziness in individual preference relation exists related to this situation. In their study, two different kinds of fuzzy-logic based calculations of linguistically quantified proposals have been used.

### 3.8. Fuzzy Sets Approach to Facility Location Selection Problem

Humans are better to make qualitative judgments comparing with the quantitative ones. On the other hand it must be added that forcing humans to make quantitative estimates make them more influenced by the biases depending on the fact that they have to perform more when estimating with numbers comparing the times when estimating with verbal expressions ( Zahedi, 1986). Fuzzy based methods have been recently emerged in such fields that verbal statements can be used as translators between verbal statements and quantitative estimates when it is a necessity to deal with the ambiguity inherent within the statement of importance for every criterion (Kahraman et al., 2003).

Conventional theories of decision making are extended or fuzzificated throughout their application of decision making area. Fuzzy based decision theories undertake a significant role to overcome the problems those are resulted from the indefinite nature inherent in the designation of alternatives, constraints and objectives (Yager, 1982). It has been further stated that to solve facility location problems traditional methods are not adequate to deal with the vagueness inherent in the verbal statements. Therefore it must be clearly indicated that the emerging trend in facility location problems is to concentrate on the fuzzy based methods (Kahraman et al., 2003).

A location model which is founded on a fuzzy multi-objective basis was suggested by Tzeng and Chen (1999). They applied this model not only to establish the number and optimal locations of fire stations at an international airport but also to determine the configuration of related responsible people within the layout. They further perform a genetic algorithm due to the complexity of their model and it was compared with enumeration approach. For the purpose of locating a store; an integrated approach of fuzzy set theory and AHP as a decision support system was proposed by Kuo et al., (2002).

A multiple criteria decision making method for distribution center selection problem under fuzziness was suggested by Chen (2001). In the related study, Chen (2001) expressed the ratings of the alternatives and the weights of criterion as linguistic variables in which later he translated them into triangular fuzzy numbers. He further designated the latest assessment value for every distribution center location as a triangular fuzzy number. In order to calculate the domination of one alternative over another, a fuzzy preference relation matrix was generated through estimating the difference of final assessment value between each pair of alternatives. Chen described the last step of his proposed methodology as a stepwise ranking procedure for the purpose of stating the ranking order for all possible alternatives. In addition to the study of Chen (2001), Kuo et al (1999) suggested a decision support system which they developed for defining the location of a store. As stated by the authors four main elements are the basis of their suggested approach which are hierarchical structure development for fuzzy AHP, determination of weights, collecting necessary data and decision making as the last step .

As stated by Kuo et al. (2002) through the first element of the suggested methodology hierarchical structure of the AHP process is designed by overlooking the related examples and interviewing with experts. In order to estimate the weights of each criterion, a questionnaire is performed while required data are collected by investigating the public documents or real researches. According to the related study, a feed forward neural network that consists of error back-propagation learning algorithm is the last step of their proposed methodology which is basically used for studying connection between factors and performance (Shen & Yu, 2009).

In many real life problems such as production planning, location selection especially when there is a lack of a certain structure such as e-commerce models, selection of necessary criterion is an imprecise process which contains full of ambiguity. Decision makers usually have to sequence the alternatives on the basis of qualitative information related with some criterion when they have to decide under these conditions (Shen & Yu, 2009). As stated by Harrison and Pelletier (2001), achieving to integrate managerial behaviors not only to the process of decision making but also to the decision itself is the key point of reaching sufficient strategic conclusions. The authors further stated that if the aim of decision maker is to end up with a proper rather than optimum output, a judgmental process provide better results than a computational process. As a result of applying the necessary plans and assessing the process, significant amount of income is gained. There are many criterions to consider such as availability of raw materials, suitable political environment, closeness to the suppliers and cultural subjects throughout the location selection (Coyle et al., 2003). As stated by Dubrin (2002), human perceptions and evaluations are the main sources of these attributes and it is not possible to calculate these values accurately. Ambiguity is a part of linguistic variables and multiple criteria decision making processes which is the reason of the uncertainties hidden in the FLS problems (Shen & Yu, 2009).

Depending on the results of an elaborate literature review, it has been realized that inadequacy of traditional methods to deal with the vagueness of the linguistic assessment has been clearly emphasized in many articles (Kahraman et al., 2003). But the point is feasibility of plant location related with many subjective criteria and the weights of these criterions are usually stated with linguistic variables. Therefore with the purpose of establishing ill-defined multiple criteria decision-making problems, fuzzy set theory is generally applied in a way that achieving to overcome the fuzziness resulted from human judgments (Liang, 1999). In their paper Ertuğrul and Nakkaşoğlu (2007) studied fuzzy AHP and fuzzy TOPSIS methods in which not only the ratings of each alternative under different criteria but also the weights of each criteria are expressed as fuzzy numbers. As further stated by the authors (2007) facility location selection literature consists of some studies that use fuzzy TOPSIS and other kinds of fuzzy multi criteria decision making methods.

Real life attributions cannot be demonstrated successfully by crisp data in many circumstances. On the other hand fuzzy approaches are considered more successful to deal with ambiguity hidden in decision making environment under the existence of imprecise information as they have the capability to serve as an instrument for the determination of preferences, objectives, limitations and group decisions (Kahraman et al., 2003). Decision making is not a process that one can always evaluate as true or false. Looking at the real life situations, it can be said that decision making is generally unregulated, argumentative and incoherent. Depending on these reasons, fuzzy approaches play an important role to solve facility location selection problems as it can be realized from the recent developments in this area (Shen& Yu, 2009). Liang and Wang (1991) proposed an algorithm which is basically stand upon the concepts of fuzzy set theory and hierarchical structure analysis of facility location selection. Furthermore a multi attribute decision making process to define provide optimal selection was developed by Liang (1999) which was built upon the conception of ideal and anti-ideal point. In the same year, an integrated decision support system was presented by Kuo, Chi and Kao (1999) in which they attempted to combine FST and AHP to select a site for a store. In addition to this research, Kuo, Chi and Kao (2002) proposed a DSS in which they integrate fuzzy AHP and ANN (artificial neural network) for the location of new stores. Chen (2001) improved a MADM method which is based upon to hierarchical ranking and is used for location selection under the existence of fuzzy variables. As indicated by Takeda (1982), the current approaches of facility location selection like AHP are not user friendly with respect to the necessity of complicated computations to solve the problem. Even though computational difficulty does not seem as a crucial problem with today's superior computers, as a disadvantage it can discourage the top management to use fuzzy MADM methods (Ölçer & Odabaşı, 2005).

The basis of the fuzzy set theory is that the main motives in the mentality of human beings are linguistic variables but not numbers (Bellman & Zadeh, 1970). It has to be added that for the purpose of assessing different alternatives to select the best choice, diversified kinds of linguistic evaluations and weights have to be combined (Chen et. al., 1992). In his paper, in order to solve DC location selection problem, Chen (1998) suggested a pair-wise preference relation based fuzzy decision making method. In his proposed method, he categorized decision criteria as quantitative and qualitative criteria. Linguistic variables that are defined by triangular numbers were used to evaluate importance weights of decision criteria and the ratings of qualitative criteria. As Chen (1998) further described his proposed method for the purpose of estimating final evaluation values of each alternative, he accumulates the ratings and the weights. By the help of comparing the current differences of final fuzzy assessment values for all possible combinations to define the over degree of preference for each pair of DC locations, a preference relation is determined. A fuzzy preference matrix was also built and for the purpose of indicating ranking order of different alternatives a stepwise ranking process was applied.

A fuzzy approach by using TOPSIS for order preference under group decisions to solve the FLS problem was introduced by Chu (2002). For the purpose of assessing facility location alternatives, Kahraman et al. (2003) developed fuzzy multi attribute group decision making methodology. Not only Chu (2002) but also Kahraman et al. (2003) suppose that the preferences of the decision makers pose equal weight. In addition to the assumption of equal importance, they also ignore the effect of the size of the decision group on group decision making problems. On the other hand neither of these two papers mentioned above considered that FLS is basically a concern of the top management level and the necessary strategically frameworks including the responsibilities of these people have to be supplied by any proposed method related with the problem of location selection. The most significant drawbacks of the models being proposed in these two papers is that first they treat decision making only a computational and operational procedure and second they obtained optimum solution without taking the principal role of the managers in to account related with the overall process (Shen & Yu, 2009). As stated by Stevenson (2005), any organization should comprehend and implement the procedures of management cycle (plan-do-check-action) while making a determination.

Dublish, Solomon, Wishart and Zanakis (1998) performed a simulation experiment to assess eight multi attribute decision making methods which are SAW, TOPSIS, MEW ( multiplicative exponential weighting), ELECTRE and four AHP's. According to the results of this simulation experiment SAW and MEW is equally the best approaches in which they are followed by TOPSIS and four AHP's whereas ELECTRE is the worst performed approach among the others. Besides above experiment of
Dublish, Solomon, Wishart and Zanakis (1998), Chang and Yeh (2001) conducted an empirical study to compare the performances of SAW, weighed product and TOPSIS. According to the results of this study, SAW has the best performance among others which can be regarded as a sign that the simpler evaluation techniques may perform better comparing to more complicated techniques.

Kahraman et al. (2003) explained their aim of preparing related research as solving facility location problems with the help of four different kinds of fuzzy multi-attribute group decision-making methods. As further explained by Kahraman et al. (2003), the first fuzzy model of these four group decision making method is proposed by Blin (1974) whereas the second one was described as a fuzzy synthetic evaluation. First of the last two methods applied is weighted goals method of Yager (1978) while the last one is a fuzzy analytic hierarchy process. They further emphasized the different origins of these four methods and different relations of them with the multi attribute group decision making while pointing out that they all possess the same goal of determining the optimum location between different alternatives. They stated that to select the best alternative, above mentioned methodologies were broadened by considering not only quantitative but also qualitative criteria. They concluded their paper with a numerical example and a comparative analysis for better understanding of the related methods.

From aspect of a company, optimal location selection is a significant process not only for cost but also for resources usage minimization (Yong, 2006). In this paper of Yong (2006), a new TOPSIS approach which can be used for the purpose of plant selection is introduced. According to their research, the ratings of the alternatives and the weights of the criteria are evaluated in linguistic terms and illustrated as fuzzy numbers. In order to ensure to work with more basic processes, triangular fuzzy numbers representations of linguistic variables are converted into crisp numbers based on the method of graded mean representation. To provide positive and negative ideal solutions multiplication operations applied on triangular fuzzy numbers. The canonical representation of these operations is used to get positive and negative ideal solutions. After calculating the distance from both the positive and negative ideal solutions concurrently, the closeness efficient is determined to generate the ranking order of all alternatives. As explained by the author himself, the difference of the proposed method from the current TOPSIS method is that it gives better results under group decision problems. On the other hand a numerical example is also provided for who wants to have better understanding of the proposed methodology.

As stated by Miller (1965), although multiple decision-makers evaluations will provide more robust decisions, it can be realized that the numbers of the researches about fuzzy MADM methods including group decision making processes are not sufficient. As pointed out by Kuo and Chen (2004), fuzzy set theory (FST) can be added to several approaches to improve the ability of dealing with the problem of ambiguity. For example Shen and Yu (2009) presented a factor rating system (FRS) which is based upon to a revised SAW. As further pointed out by authors, there are any studies that attempted to combine FST and FRS to solve fuzzy MADM problems including group decision making processes. They further emphasized that providing a judgmental framework for strategic MADM under group decision making is significant from the managerial point of view in which they emphasized the importance of a framework consisting of a simple generalized fuzzy FRS that includes a group decision making procedure for the solution of strategic FLS problem.

Fuzzy approaches were also applied to solve problems at strategic level of facility location selection as in the paper of Shen and Yu (2009) in their related paper. They explained their incentive to make a generalized fuzzy approach for strategic problems as providing a fuzzy decision making methodology for FLS problem under the existence of group decision making. As stated by the same authors, FLS problem can also be considered as a fuzzy multiple attribute GDM problem from a methodical point of view in which fuzzy assessments and the opinions of the multiple experts are taken in to account. As further explained by Shen and Yu (2009), solution methodology that they proposed for general strategic problems should practically possess five characteristics and they expressed these as follows: To begin with decision system must be consistent with strategic necessities and the context of the decisions. Secondly, ratings of the multiple alternatives and the weights of multiple attributes can be collaborated with fuzzy variables. Thirdly they have stated that it is not certainly necessary that the weights of the importance for different decision makers on some attributes and on the ratings of the alternatives should be uniformly distributed. Fourth of all, it has been emphasized that the method must take the final decision makers responsibilities related with the decision making into account. Fifth characteristic of their methodology is that while trying to decide in an efficient manner, the problem can be broken down to gain from further plans of implementation and the costs of evaluation without a crucial loss of quality under uncertain conditions for decision making.

The objective function of the facility location problem can be min-sum type or min-max type. Min-max models aim to minimize maximum distances whereas min-sum models are performed to minimize average distances (Zimmermann, 2001). Most of the researches that can be found in the literature deal with the facility location problem under the assumption that the problem parameters are known and there is no uncertainty. But it is not always easy to say that the problem parameters are certainly known in real life. When there is lack of certainty, fuzzy theory is used (Zadeh, 1975). There are many applications of fuzzy theory for location planning for facilities. For instance an algorithm which is based on fuzzy theory and hierarchical structure analysis for facility site selection was developed by Liang and Wang (1991). A fuzzy multi-attribute decision making method for distribution center location selection problem was improved by Chen (1998). In order to figure out facility location selection problem under group decision making, a fuzzy TOPSIS model is proposed by Chu (2002). To assess facility location, fuzzy multi-attribute group decision making approach was presented by Kahraman et al. (2003). With the purpose of evaluating an international distribution center environmentally, a fuzzy SWOT process was proposed by Lin and Lee (2008). Furthermore Chou et al. (2008) developed a fuzzy simple additive weighting system for facility location selection under group decision making.

In the following section; fuzzy sets, linguistic variables and fuzzy numbers will be explained and selected methodologies of fuzzy TOPSIS and fuzzy AHP methodologies will be explained in details and these methodologies will be further applied to solve facility location selection problem of a company in white goods sector.

### 3.8.1. Fuzzy Sets

Fuzzy set theory was firstly introduced by Zadeh (1965) for the purpose of dealing with the uncertainty of human mind. As further indicated by Zadeh (1965), a fuzzy set can be defined as a set of objects in which each object is specified with a grade of membership that can take values changing between zero and one. A fuzzy set is also an extended version of a crisp set. The difference is that a crisp set only allows full or none membership whereas partial membership is also possible in fuzzy sets (Ertuğrul & Karakaşoğlu, 2006). Fuzzy logic and fuzzy set theory are extremely useful mathematical tools to assist modeling systems with ambiguity and to facilitate decision making process when there is a lack of complete and definite data. When it is rather difficult to solve problem with conventional methods under the objective of attaining a good solution, the function of fuzzy logic turns out to be more crucial (Bojadziev & Bojadziev, 1998). Fuzzy set theory is more capable of picturing real life data as it has a wider framework comparing to classic sets theory (Ertuğrul & Tuş, 2007). It was proved that applying fuzzy set theory to formulate decision problems is an efficient solution approach under the existence of indefinite and subjective information (Zimmermann, 1992).

### 3.8.2. Linguistic Variable

The values of linguistic variables can be either words or sentences in a natural / artificial language (Zadeh, 1975). For instance the variable age is regarded as a linguistic fuzzy variable when it is represented as young, very young not young instead of using numbers such as 0, 1, 2, (Bellman & Zadeh, 1977). Idea of applying linguistic variables ensures the ease of process under such circumstances that a situation is highly complicated or ill-defined and really hard to define it with traditional quantitative approaches. The main application field of fuzzy-based methodologies is mostly human related such as linguistic, human decision processes, law and psychology and related areas (Zadeh, 1975).

### 3.8.3. Fuzzy Numbers

As stated by Ertuğrul and Karakaşoğlu (2007), a fuzzy number Ň is a convex normalized fuzzy set Ň of the real line R such that:

* It is available as if x0 ε R with $\mu_{\check{N}}(x_0) = 1$ ($x_0$ indicates the mean value of Ň)
* $\mu_{\check{N}}(x)$ is said to be a piecewise function.

Different kind of fuzzy numbers suitable for different situations can be used. However in most cases triangular fuzzy numbers (TFN) are frequently preferred as they have the capability of computational easiness and as they are more beneficial to represent information flow in a fuzzy environment. In this study, triangular fuzzy numbers are integrated to selected fuzzy AHP and fuzzy TOPSIS methods. A triangular fuzzy number is represented by three different indicators as (l, m, u) in which they demonstrate smallest, most possible and the largest values to model a fuzzy event. In the figure below a fuzzy number of $\tilde{M}$ is represented (Deng, 1999).

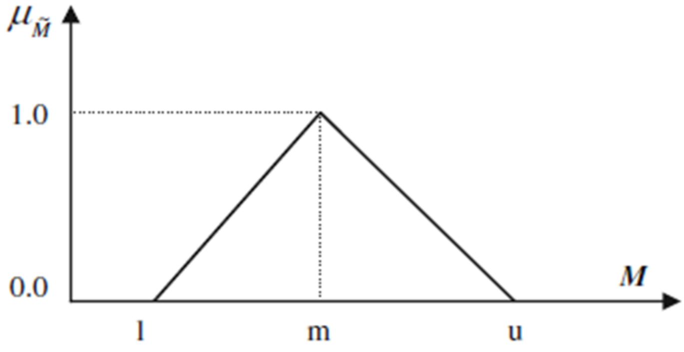


**Figure 3.1:** Triangular fuzzy number

Although there are various operations can be identified on triangular fuzzy numbers, only important ones those are used in this study will be introduced. If two different positive triangular fuzzy numbers are identified as $(l_1, m_1, u_1)$ and $(l_2, m_2, u_2)$ then it is possible to write following equations:

$$(l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1+l_2, m_1+m_2, u_1+u_2) \quad (3.1)$$

$$(l_1, m_1, u_1) . (l_2, m_2, u_2) = (l_1.l_2, m.m_2, u_1.u_2) \quad (3.2)$$

$$(l_1, m_1, u_1)^{-1} \approx (1/u_1, 1/m_1, 1/l_1) \quad (3.3)$$

$$(l_1, m_1, u_1).k = (l_1k, m_1k, u_1k) \text{ (k is a positive real number)} \quad (3.4)$$

Additionally, vertex method is used in order to calculate distance between two triangular fuzzy numbers (Saaty, 1980).

$$d_v(\tilde{a}, \tilde{u}) = \sqrt{\frac{1}{3}\,(l1 - l2)^2 + (m1 - m2)^2 + (u1 - u2)^2} \quad (3.5)$$

### 3.9. Analogous Problems with Facility Location Selection

The concept of location selection problem is basically concerned with determining the most suitable alternative among a set of points in such a way to satisfy requirements of users by taking several criteria in to account and also by paying attention to a set of constraints (Tuzkaya et al.,). There are various applications of facility location models (Perez et al., 2004). Examples of these applications are positioning the warehouses among logistics network to minimize the total transport costs, locating the hazardous materials in a way that lessening the risk of exposure to the public and locating the bus stations to minimize the diversity of the timetable (Hale and Moderg, 2003). In the following section, some applications of facility location models will be introduced.

Many studies of distribution center location selection can also be found in an elaborate literature review. Distribution center selection which can also be associated with facility location selection is a typical problem that companies frequently confronted with and have to be elaborately investigated while making a research about facility location selection. Advantages of economies of scale and transportation costs are the basic reasons of the interest for this issue. Depending on the fact that distribution centers have the possibility to assist attaining advantages among other firms, related studies about this issue is gradually increasing (Chen, 1998).

Many studies of distribution center location selection those can be solved with similar methods of facility location selection can also been found in an elaborate literature review. For example, Chou and Ou (2009) proposed a weighted fuzzy factor rating system (FRS) for the solution of international distribution center selection problem from the aspect of a foreign market. In their research they also provided an assessment procedure in order to show that the proposed methodology is an effective one under group decision making process. They explained the difference of their methodology from the existing ones as the integration of fuzzy weighting for the evaluation of individual preferences of decision makers which can be useful attribute for managers as they can take the experience of every decision maker in to account throughout the procedure of decision making.

It has to be stated that distribution center selection has strategic importance for many companies as in the case of facility location selection problems (Ou & Chou, 2009). The study of Chen-Tung Chen (1998) which was published is an example of these studies. As stated by the author; he presented a new multiple criteria decision making method for solving distribution center location selection problem which was expected to overcome the ambiguity resulted from the human judgments. As further explained by Chen-Tung Chen (1998), linguistic variables are used to describe the ratings of alternatives and the weights of criterion which will also be indicated as triangular fuzzy numbers. Furthermore, triangular fuzzy number is also necessary to express the conclusive assessment of each location. With the purpose of displaying the strength of the preferences of one plant location over another, a fuzzy preference relation matrix is constituted by estimating the difference of conclusive evaluation value among each pair of locations. On the next step of the related approach, a step by step ranking process is suggested in order to define the ranking order of alternatives.

Choosing the best distribution center between many alternatives when there are more than two factors is a multi-criteria decision making problem. It is rarely the case that the accurate values of qualitative criteria are assigned. Usually linguistic terms such as low, medium and high are used in order to describe importance weight of criteria. Therefore it has been stated by many authors that quantifying the rating of each alternative definitely is not possible when dealing with location selection problem. The fuzziness inherent in the nature of distribution center selection problems are the motivating power of many researchers to study on fuzzy decision making methods (Chen, 1998).

In their article, Ou and Chou (2009) made a study to find three aspects of fuzzy decision making procedure for international distribution center selection from a foreign market point of view . As further explained by the authors, the procedure starts with defining criteria which are necessary to assess an international DC. Second of all, they further stated that when fuzzy evaluations and opinions of various experts are taken in to account, the significance weights of each decision maker on particular attributes and criteria are not need to be necessarily uniform. In the third place, they indicated that their proposed decision support system which works basically on the principal of a simple fuzzy algorithm to assess criterions and alternatives of possible distribution centers are performed. Moreover; as emphasized by the authors their study has importance as it assists to enlighten the detected relative importance of alternative criteria related with the international DC selection decision making. Looking at the logistics side, in order to increase supply chain management efficiency and to reduce transportation cost, selecting the most appropriate distribution center selection can be regarded as one of the vital decision areas (Chen, 1998).

On the other hand, literature also consists of some problems that attempt to select locations for undesirable facilities. As explained by Rodriguez et al. (2006), facilities can be classified in to two main groups as the ones desirable those have to be located close to the users or the ones undesirable those have to be located distant. The examples of undesirable locations can be chemical plants, garbage dumping sites or polluting plants as indicated by Colebrook and Sicilia (2007). As explained by Tuzkaya et al. (2008) selecting undesirable facility location is a complicated procedure in which decision makers have to consider many criteria and constraints like governmental and environmental regulations. In the literature there can be also found some valuable researches related with undesirable facility selection.

Multiple-criteria decision making approaches were also used for urban distribution center selection problems as in the study of Awasthi et al. (2007) in their related article of “A multi-criteria decision-making approach for location planning for urban distribution centers under uncertainty.” It is a certain fact that the rise of traffic congestion in urban areas in the last years has badly affected the living conditions and it makes it obligatory to conduct some regulations like dedicated delivery zones. A distribution center which is close to customer will increase traffic on the other hand a distant one is the reason of high costs. It can be seen that it is a hard decision which has to cover many aspects of the problem like maximum customer coverage, environment friendly, minimum cost and etc.

In this paper in order to model decision making fuzzy theory is used. Fuzzy set theory is useful to model systems which are hard to identify. It was introduced by Zadeh (1965) to overcome the ambiguity in decision making process. Instead of exact numerical values, linguistic terms are used to identify parameters in such systems that Fuzzy Set Theory can be applied. As an instance city residents can define the impact of motor traffic as high, very high and low which have to be all evaluated as a linguistic variable. These linguistic scales have to be turned in to fuzzy numbers by using linguistic scales. This problem can be considered as a special situation of the more general facility location problem. In the facility location problem, there is usually a set of alternatives. These alternatives are evaluated against a set weighted criteria those are independent from each other. The best performing criteria among the others is chosen. Why this is a special case of facility location problem is that the interests of all stakeholders have to be taken in to account. On the other hand the aim is much wider than cost minimizing. Freight regulations, environment and the conditions of the residents have the impact on the decisions as well (Awasthi et al., 2011).

Tuzkaya et al. (2008) argued that placement of an undesirable facility is a complicated problem since the assessment process includes many objectives to fulfill and there is a necessity for a negotiation among many opposing criteria. In the same research they emphasized that they attempt to call attention to the problem of undesirable facility location selection by utilizing analytic network process which is a multi-criteria decision making technique. According to their explanation ANP technique has been preferred not only because it serves as a beneficial tool to evaluate quantitative and qualitative criteria simultaneously but also it is advantageous to obtain necessary observations and assessments. There are many criteria such as benefits, opportunities, costs and risks and sub-criteria have to be considered for facility location selection. In their research Tuzkaya et al. (2008) determined the criteria and their weights throughout the interviews with the experts.  They further stated that they assess 4 different locations to select the most suitable one and complete their research with a sensitivity analysis. These kinds of studies like undesirable facility location selection have importance since they can lead to provide a different aspect to apply in facility location selection problem.

# 4. SELECTED METHODOLOGIES

Facility location selection is a multi-criteria decision making problem that is strategically important from the point of many companies. Existing methods proposed for the solution of facility location selection are not satisfactory depending on the ambiguity which is resulted from linguistic nature of evaluation. In order to handle with the vagueness inherent in facility location problems, fuzzy multi criteria decision making problems are presented. In the literature there are many researches those attempted to solve FLP by using fuzzy based researches (Ertuğrul & Karakaşoğlu, 2008). For example, Ertuğrul and Karakaşoğlu (2008) applied fuzzy AHP and fuzzy TOPSIS methods for facility location selection problem of a company in their related research paper.

Fuzzy TOPSIS and fuzzy AHP methodologies are selected to solve location selection problem in the thesis. Fuzzy methods are selected on purpose in order to overcome the ambiguity resulted from linguistic assessment in which fuzzy AHP and TOPSIS are the most frequently used methods. To compare the results and the easiness of the application, there is a strong need to repeat the selection procedure with two different methodologies. The results will be further compared after applying each of the related methodologies consecutively. In the following section fuzzy AHP and TOPSIS methods and necessary steps to apply these methodologies will be mentioned and will further be applied in details in the application field of thesis.

## 4.1. Fuzzy TOPSIS

TOPSIS is an approach which is extensively used for facility location selection problems. Hwang and Yoon (1981) were the first researchers to introduce TOPSIS (the technique for order preference by similarity to an ideal solution) which is also one of the most popular MCDM methods . The concept of this method is that ideal alternative has the best and negative ideal has the worst level among all alternatives taken in to account (Yong, 2006). TOPSIS can be applied effectively to facility location selection problems. Solutions are defined as points which are closest to positive ideal and farthest from negative ideal solutions (Ertuğrul & Karakaşoğlu, 2008).

TOPSIS is also described as a method which chooses the alternative that is closest to the positive ideal solution and farthest from the negative ideal solution. A positive ideal solution is the one which includes best performance values. On the other hand, negative ideal solution is composed of the worst performance values. Many applications of fuzzy TOPSIS can be found in the literature. In the common TOPSIS method, weights of the criteria and the performance ratings are represented as crisp values. Therefore the ambiguity involved in human perception cannot be transferred efficiently to the measurement of weights and qualitative attributes (Ertuğrul & Karakaşoğlu, 2006). As the attributes and the weights of the attributes are often denoted by linguistic variables, crisp data are often inadequate to model real life problems (Shen & Yu, 2009). This is the reason why there is a need for a new approach for the evaluation of linguistic variables. This need for an approach that takes the uncertainties in to account triggered some researchers to concentrating on fuzzy TOPSIS to solve plant location (Chu, 2002). In the literature fuzzy TOPSIS approach has further been developed by many researchers. For example in their paper, Yong (2005) has proposed a new fuzzy TOPSIS approach. In his article Yong (2005) has emphasized that as fuzzy ranking approaches are used for ranking fuzzy positive and negative ideal solutions, any current fuzzy TOPSIS methods can be considered as efficient methodologies to solve FL problem depending on the common fact that any fuzzy numbers can be ranked with a satisfactory result. The author has further stated that calculating the distances from the ideal and negative ideal is also a time consuming process in addition to the ranking problem of existing TOPSIS approaches. In the article it has been strongly remarked that the major incentive of developing a new fuzzy TOPSIS approach is to overcome these difficulties. In their method, triangular fuzzy numbers are representative for the ratings of alternatives and the weights of criterion. According to the related article the results of the multiplication of ratings and the weights can be expressed in crisp numbers through the help of the canonical representation of multiplication operations on fuzzy numbers. Then without a need for sequencing fuzzy numbers, fuzzy positive and negative ideal solutions are defined. In the next step of the proposed approach the distance from the ideal and the negative ideal solution should be calculated which can be also achieved easier compared to current approaches (Yong, 2005). As further stated by Yong, the aim of proposing a new method beside general TOPSIS is to handle with linguistic variables in facility location selection problems by decreasing the computational complexity.

Fuzzy TOPSIS method is not only applied to facility location selection but also distribution center selection problems as well. To make a proper location planning in order to minimize distribution costs and traffic problem which is resulted from goods moving from one place to another is really important. In the article of Awasthi et al., (2007) a multi-criteria decision making method under ambiguity is proposed for urban distribution centers. The represented method consists of determination of location alternatives, applying fuzzy theory with the purpose of weighting criterions and applying fuzzy TOPSIS to choose the best location for a distribution center. Furthermore sensitivity analysis is conducted to identify the effects of the weights on location planning decisions and a numerical application is also provided.

In this paper, Fuzzy TOPSIS method which was formerly proposed by Chen et al., (2006) in their related paper of "*A fuzzy approach for supplier evaluation and selection in supply chain management"* will be applied to solve facility location problem. The basics of fuzzy logic and fuzzy set theory were introduced in previous section. In this section first of all necessary tables to convert linguistic variables in to triangular fuzzy numbers will be introduced and second of all the proposed methodology will be elaborately explained step by step.

### 4.1.1. Converting Linguistic Variables in to Triangular Fuzzy Numbers

Linguistic variables are those which are expressed with words. Importance weights of various criteria and evaluation of alternatives with respect to related criteria are conducted as linguistic variables according to the fuzzy TOPSIS methodology. Appropriate linguistic variables are required for the purpose of evaluating importance weights of decision criteria and evaluation of alternatives with respect to these criteria. In order to express linguistic variables as triangular fuzzy numbers following tables of 4.1 and 4.2 are required.

Seven point linguistic scales in table 4.1 and 4.2 were developed and applied in fuzzy TOPSIS method by Chen (2000). However there are other studies in the literature those applied 3, 5 or 9 point linguistic scales. As pointed out by Eleren (2007), procedures turn out to be more sensitive as the point of scales are increased and less sensitive in the opposing situation. As stated by Chen et al., (2008) seven-point linguistic scales are still in use to convert linguistic variables in to triangular fuzzy numbers.

**Table 4.1:** Linguistic variables for importance weight of each criterion (Ertuğrul & Karakaşoğlu, 2007)

| Linguistic Variables | Triangular Fuzzy Numbers |
|---|---|
| Very low (VL) | (0, 0, 0.2) |
| Low (L) | (0.1, 0.2, 0.3) |
| Medium Low (ML) | (0.2, 0.35, 0.5) |
| Medium (M) | (0.4, 0.5, 0.6) |
| Medium High (MH) | (0.5, 0.65, 0.8) |
| High (H) | (0.7, 0.8, 0.9) |
| Very High (VH) | (0.8, 1, 1) |

**Table 4.2:** Linguistic Variables for ratings

| Linguistic Variables | Triangular Fuzzy Numbers |
|---|---|
| Very poor (VP) | (0, 0, 2) |
| Poor (P) | (1, 2, 3) |
| Medium Poor (MP) | (2, 3.5, 5) |
| Fair (F) | (4, 5, 6) |
| Medium Good (MG) | (5, 6.5, 8) |
| Good (G) | (7, 8, 9) |
| Very Good (VG) | (8, 10, 10) |

In fuzzy TOPSIS methodology, importance weight of criteria can be identified either directly by decision-makers or by other methods. In this study, determination the importance weight of criteria and assessment of alternatives with respect to criteria will be performed by using table 4.1 and 4.2 as proposed by the related model of Chen (2000).

### 4.1.2. Fuzzy TOPSIS Methodology

In the following section, the basic steps of proposed methodology will be introduced consecutively which are as follows:

1. As it is a group decision making problem, first of all there is a need to decide on decision makers. Under the fact that there exists K number of decision-makers $D_k$=(k=1,2,...K) is representative to fuzzy rating of each and every decision-maker whereas $\check{R}_k$=(k=1,2,...K) is representative of these values by triangular fuzzy number with a membership function of $\mu_{\check{R}k}$ (x).

2. In the next step necessary criteria to make evaluations are defined.

3. As a consequent step to assess criteria and alternatives, proper linguistic variables are selected.

4. Last of all, weight of criteria are cumulated.

It has to be added that cumulated fuzzy ratings of decision-makers are demonstrated as Ř = (a, b, c), k=1,2,3,4,..., when fuzzy ratings of all decision-makers are represented as $Ř_k$ = ($a_k$, $b_k$, $c_k$), k=1,2,3,4,..,K. The required equations to conduct the process in this step are:

$$a = min_k\{a_k\}, \quad b = \frac{1}{K}\sum_{k=1}^{K} b_k, \quad c = max_k\{c_k\} \tag{4.1}$$

Accumulated fuzzy ratings of ($X_{ij}$) of alternatives with respect to each criterion can be found as ($X_{ij}$) = ($a_{ij}$, $b_{ij}$, $c_{ij}$) when the fuzzy rating of the *k* the decision-maker are $x_{ijk}$ = ($a_{ijk}$, $b_{ijk}$, $c_{ijk}$) whereas importance weight of it is $\hat{W}_{ijk}$ = ($w_{jk1}$, $w_{jk2}$, $w_{jk3}$), i = 1,2,.., m and j = 1,2,...n in a relative manner. Following equations should be used in this step of the algorithm:

$$a_{ij} = min_k\{a_{ijk}\}, \quad b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ijk}, \quad c_{ij} = max_k\{c_{ijk}\} \tag{4.2}$$

After that accumulated fuzzy weight of each criterion are calculated as:
($\hat{W}_j$) = ($\hat{w}_{j1}$, $\hat{w}_{j2}$, $\hat{w}_{j3}$) in which following equations are applied.

$$w_{j1} = min_k\{w_{jk1}\}, \quad w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{jk2}, \quad w_{j3} = max_k\{w_{jk3}\} \tag{4.3}$$

5. Fuzzy decision matrix is constructed in this step of the algorithm which can also be shown as:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \tag{4.4}$$

$$\hat{W} = [\hat{w}_1, \hat{w}_2, \ldots, \hat{w}_n]$$

In this step of the methodology for i = 1, 2,... m and j = 1,2,...n;

$(X_{ij}) = (a_{ij}, b_{ij}, c_{ij})$ and $(\hat{w}_j) = (\hat{w}_{j1}, \hat{w}_{j2}, w_{j3})$ can also be resembled to positive triangular fuzzy numbers.

6. Decision matrix is normalized in the sixth step of the algorithm. In order to converting criteria scales in to a comparable scale, linear scale transformation can be used instead of normalization formula of traditional TOPSIS which is very complex. As explained by Chen (2000), it is aimed to normalize fuzzy decision matrix Ř through this step of the algorithm.

$$\tilde{R} = [\tilde{r}_{ij}]_{m\,x\,n} \quad i = 1,2,\ldots,m,\ j = 1,2,\ldots,n \tag{4.5}$$

Where:

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \tag{4.6}$$

$$c_j^* = max_i c_{ij} \tag{4.7}$$

7. By multiplying importance weights of assessment criteria and the values of fuzzy decision matrix which was normalized in the former step, weighted normalized decision matrix is generated in such a manner that the different weight of each criterion also have to be taken in to account. Weighted normalized decision matrix $\tilde{V}$ is demonstrated as follows:

$$\tilde{V} = [\tilde{v}_{ij}]_{m\,x\,n} \quad i = 1,2,\ldots,m,\ j = 1,2,\ldots,n \tag{4.8}$$

$$\tilde{v}_{ij} = \tilde{r}_{ij}(.)\tilde{w}_j \tag{4.9}$$

The importance criterion of $C_j$ is demonstrated by $\tilde{w}_j$ in the above equations. On the other hand for each and every i and j, normalized positive triangular fuzzy numbers can also be approximate the related elements $\tilde{v}_{ij}$ with respect to weighted normalized fuzzy decision matrix.

8. As explained by Chen et al., (2006), in this step of the algorithm fuzzy positive ideal solution (FPIS, $A^*$) and fuzzy negative ideal solution (FNIS, $A^-$) have to be calculated and demonstrated as they are in the following representations.

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots \tilde{v}_n^*) \quad (4.10a)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots \tilde{v}_n^-) \quad (4.10b)$$

Where:

$$\tilde{v}_j^* = max_i\{v_{ij3}\} \quad (4.11a)$$

$$\tilde{v}_j^- = min_i\{v_{ij1}\} \quad i = 1,2,\dots,m,\ j = 1,2,\dots,n. \quad (4.11a)$$

9. According to the 9th step of the algorithm the aim is to calculate the distance of each alternative from FPIS and FNIS through the implementation of following equations in which $d_v$ (...) represent the measure of distance between two fuzzy numbers.

$$d_i^* = \sum_{j=1}^{n} d_v(\tilde{v}_{ij,}\ \tilde{v}_j^*) \quad i = 1,2,\dots,m \quad (4.12a)$$

$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij,}\ \tilde{v}_j^*) \quad i = 1,2,\dots,m \quad (4.12b)$$

10. With the objective of ranking all possible alternatives ($CC_i$) which is concurrently the distances to fuzzy positive ideal ($A^*$) and negative ideal ($A^-$) solutions and defined as closeness coefficient has to be calculated. As taken from Chen (2000), required

equation to calculate closeness coefficient of each alternative is given with the following formula:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad i = 1,2,\ldots,m \qquad (4.13)$$

11. The ranking of the alternatives are calculated with respect to the results of closeness coefficients. With respect to the above equation of 4.13 that has to be used to calculate the closeness coefficient, it is so clear that the optimal solution is in such a distance which is closer to FPIS and farter to FNIS.

The algorithm of fuzzy TOPSIS method proposed by Chen (2000) was elaborately mentioned in the above sections. With the objective of providing an overall view the basic steps of the proposed approach is summarized in the following table 4.3:

**Table 4.3:** The basic steps of proposed fuzzy TOPSIS methodology of Chen (Ertuğrul& Karakaşoğlu, 2007)

| |
|---|
| * Selecting the proper linguistic variables |
| * Accumulating the weight of criteria |
| * Ranking alternatives with respect to their coefficient of closeness. |
| * Normalizing fuzzy decision matrix |
| * Structuring weighted normalized fuzzy decision matrix |
| * Determination of FPIS and FNIS values |
| * Calculation of distances from FPIS and FNIS for each alternative |
| * Calculation of closeness coefficient for each alternative. |
| * Structuring fuzzy decision matrix |

## 4.2. Fuzzy AHP

AHP is especially useful to configure multiple criteria decision making problems as a hierarchical structure (Kahraman et al., 2003). The most important benefit of this technique is that it is extensively adjustable and can be exercised in a wide range of circumstances (Kuo et al., 2002). AHP is extensively used when decision maker has to choose between many alternatives under the existence of opposing criteria. It has to be kept in mind that the importance of the decision criteria depends on the perception and the preference levels of the decision maker (Badri, 1998). As stated by Zahedi, AHP is helpful to prevent inconsistency of selection problems in which decision criteria are based on the views of experts and are represented in a subjective manner (1986). This attribute of AHP makes it appropriate to use for location selection problem. The evaluations of facility planning decision makers are revealed in a methodical and rational way by using AHP. As a complicated planning problem, AHP facilitate the procedure of capturing group judgments' in a highly dynamic environment (Badri, 1998). The framework of AHP was firstly defined by Saaty (1980). To start with, the problem is exhibited graphically with respect to criteria, alternatives and the objectives which is an important step to give a description of the problem. In a typical problem hierarchy, the first level demonstrates the object of the problem which is to choose best location in facility location selection problems. In the second level, criteria which are important to accomplish main goal have to be determined. Defining the location alternatives takes place in the final step. AHP method consists of specific opinions of decision makers which are related with the relative significance of each criterion concerning their contributions to fulfill the objective. Preferences of decision makers for each alternative with respect to their contributions to each criterion are determined in later steps (Badri, 1998).

It is also possible and beneficial to apply a sensitivity analysis after these methodologies. The aim of sensitivity analysis is to define how sensitive is the overall decision to the small changes of the individual weights which were assigned in the pair-wise comparison process. In order to understand the sensitivity of the decision, the values of the weights are altered to some degree with the purpose of recognizing the effects of the change on the decision (Averbakh& Berman, 1997).

The first step of establishing a new facility is to select the best location among the alternatives. As explained by Aydın, multi-criteria decision-making methods have to be applied to make the selection related with the fact that optimization a number of criteria is required for completing selection process. Quantitative data that has been either provided by surveys or expert opinions are necessary to make selection.

Analytic hierarchy process is a widely preferred multiple-criteria decision making tool which was introduced by Thomas L. Saaty as previously stated (1980). It has to be emphasized that conventional AHP is not adequate to capture and reflect the way of human thinking (Kahraman et al., 2003) this is because it uses exact values in order to exhibit assessment of decision makers during the comparison of different alternatives (Wang & Chen, 2007).

The steps of Fuzzy AHP methodology will be explained in following section.

### 4.2.1. Fuzzy AHP Methodology

There are four basic assumptions to solve location selection problem through fuzzy AHP models as explained by Yang & Lee (1997). First of these assumptions is the existence of necessary data when the problem consists of a complicated location selection model. Second assumption is that decision-makers are equipped with enough information about geographic conditions of alternatives whereas third assumption is that they have information about variables so that they can evaluate the strong sides of the alternatives. Last assumption is that the managerial judgments and views of the experts should be acknowledged as inputs related with the process of solution.

In this thesis, extent fuzzy AHP method which was firstly presented by Chang in 1996 will be applied to solve facility location selection problem. Before starting with the steps of the methodology, necessary definitions have to be expressed. To begin with let assume that;

X ={x1, x2, x3,.......,xn} as an object set

G = {g1, g2, g3,.......,gn} as a goal set.

Then, each object is taken and for each goal extent analysis is consecutively conducted. After that it can be noticed that for each object m extent analysis is collected and they can be represented as following:

$M_{gi}^{1}$, $M_{gi}^{2}$,...............$M_{gi}^{m}$ i = 1,2.....,n.

It has to be stated that each and every $M_{gi}^{j}$(j = 1, 2...m) are triangular fuzzy numbers. After describing the necessary definitions, the algorithm of Chang's (1996) extent analysis will be summarized through the following section of the thesis.

1. The value of fuzzy synthetic extent with respect to the object can be defined with the following equation:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \ x \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \tag{4.14}$$

The following fuzzy addition operation of m extent analysis is conducted in order to attain $\sum_{j=1}^{m} M_{gi}^{j}$ as follows:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{4.15}$$

On the other hand, fuzzy addition operation of $M_{gi}^{J}$ for j=1, 2, m has to be conducted with respect to following first equation of (4.17) in order to attain $[\sum_{j=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}]^{-1}$. After that the following second equation of (4.18) has to be conducted to compute the inverse of the vector obtained by applying equation (4.17).

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i , \sum_{i=1}^{n} m_i , \sum_{i=1}^{n} u_i\right) \quad (4.16)$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (4.17)$$

2. $M_1$ and $M_2$ are two triangular fuzzy numbers and can be represented as follows: $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$

Under these circumstances degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ can be determined with equation 4.18 and can be expressed with equation 4.19 as follows:

$$V(M_2 \geq M_1) = sup_{y \geq x}\left[\min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \quad (4.18)$$

and can be expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) \quad (4.19)$$

$$\begin{cases} 1, \; if \; m_2 \geq m_1 \\ 0, \; if \; l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2)-(m_1 - l_1)}, \end{cases} \quad (4.20)$$

In the following figure of 4.1, intersection between $M_1$ and $M_2$ are represented in which D is the highest intersection point between $M_{\mu 1} - M_{\mu 2}$ and d is the ordinate value of this point.

It has to be stated that to compare $M_1$ and $M_2$, both values of V ($M_1 \geq M_2$) and V ($M_2 \geq M_1$) are required.

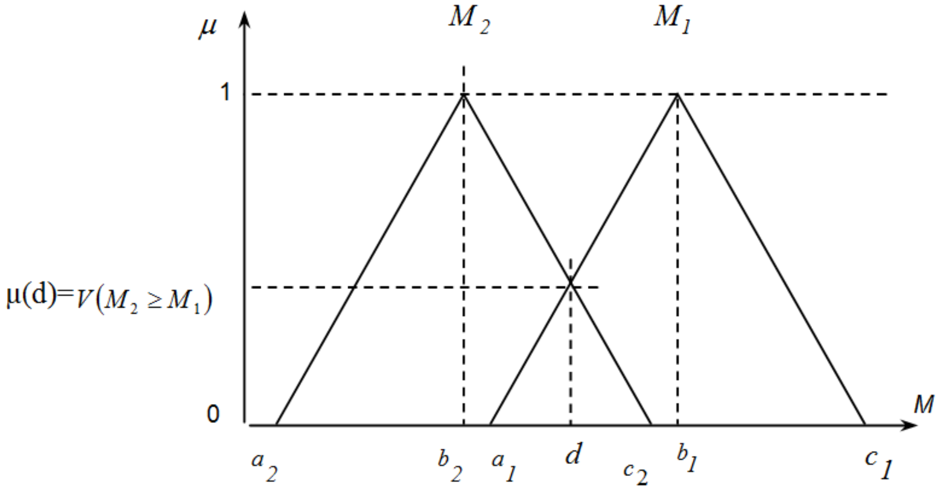


**Figure 4.1:** Intersection of $M_1$ and $M_2$

3. To define possibility degree of a convex fuzzy number to be greater than k convex fuzzy $M_i$ (i=1, 2, k) numbers following equations.

$$V\ (M \geq M_1, M_2 \ldots M_k) \quad (4.21a)$$

$$V\ [(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \ldots \text{ and } (M \geq M_k)] \quad (4.21b)$$

$$\text{Min } V\ (M \geq M_i),\ i = 1, 2, 3 \ldots k \quad (4.21c)$$

Weight vector is given by the following equation of 4.22 under the assumption that for k=1, 2... N; $k \neq i$; $d(A_i) = \min V\ (S_i \geq S_k)$

$$W^{'} = (d'(A_1), d'(A_2), \ldots d'(A_n))^T \quad (4.22)$$

Here it has to be stated that there exists n elements in set of $A_i$ = (i=1, 2… n).

4. In the last step of the algorithm normalized weight vectors are generated via normalization as follows in which it has to be pointed out that W is a non-fuzzy number.

$$W = (d\ (A_1), d\ (A_2) \ldots d\ (A_n))^T \quad (4.23)$$

It has to be added that comprehensive pair-wise comparison matrix which is generated by integrating three decision-makers evaluations as it is in table 7.16 has to be transformed into triangular fuzzy numbers by using below equation:

$$l_{je} = \min (b_{jep}) \quad (4.24a)$$

$$m_{je} = \frac{\sum_{p=1}^{t} b_{jep}}{p} \quad (4.24b)$$

$$u_{je} = \max (b_{jep}) \quad (4.24c)$$

$p = 1,2,..t$ $j= 1,2, ..m$ $e = 1, 2, \ldots m$

# 5. FACILITY LAYOUT DESIGN APPLICATION

Two essential subjects that will be considered throughout the thesis will be facility location selection and facility layout design problems. Aim of the first part of this study was to present an elaborate literature review about these two different subjects. With this main objective, problem definitions, content of the problems, past studies, solution methodologies and other significant aspects of the subjects were considered step by step. In the following sections of thesis, first of all company will be introduced basically, process charts will be presented, current situation will be analyzed and departments with highest material flow will be determined. Based on these data, from to charts and transportation costs matrixes will be prepared. In the next step; CRAFT which is commercial software to determine best layout alternative on the basis of transportation cost will be used. Product groups, main departmental areas and some other necessary information will also be provided for readers to evaluate the study. Excel based CRAFT will be applied to solve facility layout design problem. Different layout alternatives based on CRAFT will be generated and the one with least transportation cost will be aimed to be attained iteratively. Second of all fuzzy TOPSIS and fuzzy AHP methods will be applied consecutively for solving facility location selection problem. The results of applied methodologies will be represented and later will be compared.

In the following sections, selected methodologies will be applied to a consumer products factory in Turkey for the purpose of solving facility layout design and facility location selection problems. By this way, the very first basic decisions and related solution methodologies to establish a facility will be determined.

## 5.1. General Characteristics of the Facility

This study was conducted in a consumer products factory in Tekirdağ location. It has to be added that the facility which covers this factory also consists of other five factories, a main building for administrative affairs a central logistics warehouse and a common dining hall.

Related factory is rather new and active not more than two and a half years. Following to four months of project process, the production had started at the last two months of 2011 in a small amount in juicer, plastic slicer and metal slicer lines in a temporary factory building. During this period till 2013, a new factory building was constructed and was completed at the beginning of the January 2013. At the same date, all the factory with its lines, warehouse and also offices were transported to the new factory building. The factory continues production as it was established in January 2013 but as can be seen by some aspects further changes in layout may provide better results in transportation costs which make it necessary to make a systematic research for the examination of current layout and also to present more efficient layout alternatives.

Currently, the factory has four different kinds of production lines which are VC_1, plastic slicer, metal slicer and blender. At the end of 2013 in December, a new VC_2 line will also be established. According to the forecasts 5000 pieces of vacuum cleaner will be produced in this month. Yearly estimated production figures of other four existing lines which were determined based on estimated sales figures can be found in below table of 5.1. It can be seen that maximum production figures will assumed to be in VC_1 line.

There are 48 blue-collar workers of the factory in which 8 of them are working in warehouse for material receiving and feeding. Currently the factory is working during two shifts. Each shift consists of eight hours in which forty minutes are dedicated to lunch and ten minutes are dedicated to tea break. There are seven different kinds of equipment for transporting materials inside the factory. All the equipment is for rent.

**Table 5.1:** Yearly estimated production figures of four different production lines

| Production Line | Production Figures (yearly) |
|---|---|
| VC_1 | 557250 |
| Plastic Slicer | 241000 |
| Metal Slicer | 124750 |
| Blender | 36500 |

### 5.2. Problem Definition

In this study a layout design process was performed in order to increase the efficiency of material movements between different departments**.** In order to conduct this study overall processes of the factory was observed regularly and in details also by collecting necessary data from responsible people for each department. The study was started with defining the current situation of the factory. It was estimated that more efficient layout designs with less transport costs are also possible. To define the basic steps of project, a general overview of the current situation is put forward. To exhibit the processes and the transport quantities between departments was determined as the starting point of a possible new design. If the number of departments is expressed with n, n(n-1)/2 are defined as the numbers of locations that can be changed in case of all the departments have a common boundary. With the purpose of ensuring the efficiency of calculation time while evaluating the layout plans based on the transport costs, an Excel based software programmed that consider.

As further indicated, the problem will be examined under two main subjects as facility location selection and facility layout design. As previously stated; production lines except VC_1 is active since 2011 in which VC_1 line has established at September 2012. The new factory building was constructed during 2012 and it is actively used since January 2013.

As a new start-up, there are many different points to be improved. All the systems for layout, material handling, packaging types and etc., have to be installed from the beginning. New studies and time are needed to complete these processes. The basic and significant problem is with inefficient layout design which will certainly affect the other crucial decisions. After moving to the new factory building it was realized that changing some of the departments can provide better results as some of the routes are unnecessarily long although material handling quantities among related departments are high comparing to the shorter paths. Therefore it is very obvious that current layout and the systems are not best fit for the overall process. The basic problem about the facility is determined as inappropriate layout design and has to be re-designed. Other studies like material flow design, line optimization, productivity improvement researches also have to be conducted following to layout design.

It has to be added that the greatest advantage of the factory is its flexibility. As a consumer products factory the production lines are not so complicated and can be transported from one place to another in case of a necessity. Lines were also formerly transported from Slovenia to Turkey when top management decided to continue their consumer products production in Turkey.

On the other hand the company has also other factories and considering building a new plastic factory to meet plastic parts requirement as in-house production. With the purpose of location selection of this new factory, fuzzy TOPSIS and fuzzy AHP methods will be in use and the results will be compared to each other.

### 5.3.1. Product Lines and Materials

It has been further stated that there are four different production lines in the factory. A fifth line of vacuum cleaner is planned to be adapted in the beginning of year 2014. According to the estimated sales figures, 5000 pieces of vacuum cleaners are planned to be produced in year 2014. There are different models for each line. Number of models and number of required materials for each production line can be seen in the following table 5.2:

**Table 5.2:** Consumer Products Factory Product Lines and Materials

| Production Line | Number of different Models in each line | Total Number of Required Materials (for 1 product) | Number of Common Materials (for 1 product) | Number of Variant Materials (for 1 product) |
|---|---|---|---|---|
| VC_1 | 22 | 160 | 41 | 119 |
| MTL_SLICER | 13 | 227 | 24 | 203 |
| PLS_SLICER | 6 | 84 | 8 | 76 |
| BLENDER | 4 | 65 | 33 | 32 |

It can be seen that proportion of variant materials and the number of materials in metal slicer line is more than other lines. Half of the materials in the factory are imported. In order to decrease logistic costs, there are many projects to localize expensive and bulk materials if possible. There are any in-house productions in current situation. All the materials are supplied from either local or abroad suppliers. The production processes only consist of assembly. On the other hand, as it will be the subject of the second part of the study, there is a project to establish a plastic injection factory to manufacture selected plastic components from all factories inside the facility.

Although number of shifts and the number of production quantities may vary depending on some special cases like a problem in the supply of some materials or tool modification in the supplier and etc., generally production figures of each line can be taken as follows:

**Table 5.3:** Production figures of each line

| Production Line | Number of Shifts (per day) | Number of Production (per shift) |
|---|---|---|
| VC_1 | 2 | 365 |
| PLS_SLICER | 1 | 550 |
| MTL_SLICER | 1 | 240 |
| BLENDER | 1 | 160 |

The factory is working 2 shifts per day in which the working hours of first shift is between 08:00 – 16:00 and the second shift is between 16:00-00:00. Factory calendar is closed on Sundays. Although it may change in every month, production lines are in work generally 24 days in a month.

### 5.3.2. Current Processes

It can be said that processes start with receiving the materials on a planned sequence from one of the six platforms existed in factory. The area next to the platforms is defined as goods receipt area. Materials are unloaded from trucks in goods receipt area by using forklifts. Finished goods, service parts, returned materials or raw materials supplied for supplier are also loaded from the same area. That’s why it is called both goods receipt and loading area.

The materials are received by the operator after a confirmation process which is basically controlling whether quantities on the box are the same as the quantities on delivery note. As soon as the goods receipt process is completed on ERP system, a message indicating that new materials are received is transmitted to incoming inspection responsible. Related operator from incoming inspection team takes 5% of materials and conduct necessary tests in the assigned area for this process which is assumed to be close to warehouse. Materials which are approved by incoming inspection are addressed randomly in one of those empty addresses of the warehouse. On the other hand, in case there are lots of mistakes in a box, related pallet is carried to the blocked material area.

Six different kinds of transport equipment are used to feed materials from warehouse to production lines. All these equipment are for rent. As a new startup, it has to be clearly stated that the factory has any skip materials which means that a defined proportion of all materials are firstly carried to the incoming inspection area and then approved materials are addressed in the warehouse and transferred to production lines. Depending on the problems in packaging conditions, only a small portion of materials can be fed by KANBAN system in current situation. Other materials are transported to production lines from the warehouse when the material coordinator of the production line demands for it. There is an area to collect finished goods from production lines which is dedicated to gather all the products in one region. A worker of the warehouse periodically transports finished goods from finished goods area to loading area when a truck is available to carry goods from loading area to central logistic depot. 33 pallets of materials can be transported by a truck whereas 15 pallets are carried by a lorry. In each shift, finished goods are randomly carried to finished goods collecting area from production lines on the basis of pallets.

Finished goods which are not approved by quality department are collected in blocked material area. On the other sometimes when there is a problem in material supply, products can be produced with a lack of some of the components and these pallets are directly transported to central logistic depot until a rework plan is arranged. In other cases if there is a common mistake in most of the finished goods of a pallet, these pallets are blocked in blocked material area and reworked at the end of the shift. Other pallets which are collected in finished goods area are transported to loading area and loaded to the trucks from the platforms. Additionally, returnable packaging materials are first carried to the returnable packaging area from production lines and later to loading area to load to the trucks from the platforms to send them to suppliers. All these processes are figured out in a more detailed way in appendix A.

## 5.4. New Layout Design Process

As previously indicated, a new layout design procedure will be presented in this section of the thesis. CRAFT, Excel-based software, which objects to minimize transportation costs by providing the user to generate different kinds of layout alternatives, will be used for the purpose of analyzing and changing current layout design. CRAFT is a heuristic procedure which determines material movements by taking mid depots (variable or fixed) and fixed points into account. Cost matrixes as well as flow matrixes should be prepared in advance to enter as an input of the software.
Depending on the fact that, the factory is a rather new one and do not have regular and information flow, some of the assumptions as can be found in the following section have been taken in to consideration to generate not only flow but also cost matrixes. Starting from following section, the logic of CRAFT software as an assistant for layout design, the procedure of how CRAFT solutions were step by step implemented to current problem and how the new layouts are generated will be explained. Furthermore; as a preliminary procedure from to charts and transportation cost matrixes related with the current layout are created with the purpose of having best solution.

### 5.4.1. Assumptions

As a new factory production figures fluctuates highly which is the basic problem of having definite data to determine transports between departments. Additionally, frequently some models are phased out and some other new models are phased in. It is also under possibility that production in slicer lines may be stopped in two or three years' time. But as all these are only some possible decisions in strategic level, only current situation including a new vacuum cleaner line will be considered in the layout which is certain to be adapted at the end of 2013.

On the other hand parameters and systems about material supply are also changing so rapidly to find the best process. Day by day, it is objected to decrease coverage day of each material with the purpose of having an acceptable stock level. It is also the case that current data cannot reflect the future position with all aspects and have to be adjusted.

These are the main reasons why there is a need to assume some of the parameters as constant. In order to simplify calculating daily average transports between different departments, following assumptions were accepted.

* Production plan which was created on the basis of 2013 estimated sales figures were used while calculating material flows between departments.

* In production plan, the number of finished goods expected to be produced in each different line for each different month are shown as the number of finished goods pallet.

* As stated by the logistic manager of the factory, roughly three pallets of material pallets are in use to produce one pallet of finished goods. Therefore, as number of finished goods was already determined, number of material pallets is multiplied by three to define the number of material pallets transported between each specified departments.

* A second vacuum cleaner line has not been established yet but it will certainly start production at the twelfth month of 2013 in which it is expected to produce 5000 pieces of vacuum cleaner in this same month.

* According to the information taken from quality control, % 5 of received materials is controlled randomly. It has been further stated by incoming inspection that averagely % 6 percent of all received materials are blocked depending on some quality issues or packaging damages.

* According to the data recorded by finished goods control team, % 3, 5 of all finished goods from each line is controlled during each production day.

* As stated by the quality control for finished goods unit, 42 % of all finished goods which are controlled have some defects and transported to blocked area.

* Packaging engineer of the factory also provided the data of percentage of returnable packaging within all production.

* Depending on the labor safety regulations, it was accepted that in its each drive, one forklift can carry one pallet.

* In the layout there is an area which is specified as LO which means that this area is rented to central logistics of the organization for a restricted time. It has to be pointed out that there are any material movements between this area and other areas. All related transports are provided by central logistics unit and costs nothing to consumer products factory.

* In current situation, there are any skip materials in the factory which means that all a small portion of all materials are controlled and addressed in warehouse. Therefore there are any material movements between product lines and goods receipt area.

**5.5. Generation of Flow and Cost Matrixes**

Craft program is used with the purpose of developing new layout designs to ensure minimum transportation costs. In this section of thesis, the main subject will be about how this software can be used and how the layouts will be generated. Additionally, first of all from to charts and transportation costs matrixes will be defined and interpreted with this purpose.

As previously stated; CRAFT defines material flows on the basis of mid-depots (variable or fixed) or fixed departments. Units which are determined to generate CRAFT solutions are as follows:

*Mid-depots*

1. VC_1 (Vacuum Cleaner 1)
2. VC_2 (Vacuum Cleaner 2)
3. Plastic Slicer
4. Metal Slicer
5. Blender
6. Central Logistic Rent Area
7. Finished Goods Collecting Area
8. Returnable Storage
9. Blocked Material
10. Incoming Inspection
12. Quality Control

*Fixed*

11. Warehouse
13. Goods Receipt = Loading Area
14. Chemical Warehouse

### 5.5.1. Generation of Flow Matrix

Current layout design is presented as appendix B. From to charts are the graphs those exhibits the material flows of transportation vehicles between different departments within a given time.

$\mathbf{v_{ij}}$**:** Number of movements from i to j in unit time
$\mathbf{u_{ij}}$**:** Cost of transporting load
$\mathbf{d_{ij}}$**:** distance between I and j
$\mathbf{y_{ij}}$**:** Cost of transport that changes depending on the quantity of transported load in unit distance ($u_{ij}$ x $v_{ij}$)

From-To chart ($v_{ij}$) on the basis of material movement between departments in unit time ($t_{ij}$);

This chart demonstrates the number of movements in one day between different departments and it can be sometimes arranged as quantity of materials which will be transported in unit time. But to fill the table on the basis of material flows will provide better results in case only one type of transport equipment is used. This chart has the same values for existing and new layouts. Because the number of movements between departments does not change by replacing them this is why related table is same for all different layouts and it will be more appropriate to show this table once. In below section; how material flows between different departments are analyzed will be exhibited and results will be integrated in flow matrix.

In this section, number of material movements between different areas will be calculated for the purpose of generating from to matrix. During this process, it was assumed that each time a forklift carries one pallet and therefore proportionally thinking, number of pallets transported between different areas will be taken as number of material movements between concerned departments. In the below section material flows between different areas will be demonstrated consecutively.

#### 5.5.1.1. Warehouse and Production Lines

As indicated by the production planner of the factory, a rough production plan for each month is prepared yearly on the basis of that year's estimated sales figures. In this section, related production figures of 2013 will be taken into account while calculating the number of material pallets transported between warehouse and production lines.

On the other hand, as further stated by the logistic manager of the factory, three pallets of material pallets required to produce one pallet of finished goods. Therefore with the purpose of calculating number of material pallets from warehouse to production lines, number of finished goods pallets will be multiplied by three. He also stated that same logic has also been used in other projects coordinated by the logistic department of the factory.

The data for number of finished goods are collected for each month whereas related numbers are divided by 24 to find these values daily as the production is active 24 days in a month. Below table 5.4, generated from monthly production plan demonstrates number of finished goods pallets transported in a day.

**Table 5.4:** Consumer Products Factory Finished Goods Pallets (pal/day)

| **Consumer Products Factory Finished Goods Pallets (pal/day)** | |
|---|---|
| **Production Type** | **2013** |
| VC_1 | 23 |
| VC_2 | 11 |
| PLS_SLICER | 6 |
| METAL_SLICER | 9 |
| BLENDER | 2 |
| TOTAL | 51 |

VC_2 line has not established yet. Depending on the project timeline this line will be active beginning from the December 2013. It was planned that 5000 pieces of vacuum cleaners will be produced in the same month whereas it was assumed that this number can increase twenty percent and the calculations are conducted on the basis of 6000 pieces of finished goods in vacuum cleaner 2 line. This tolerance value was added with respect to the experiences of a 20 % rise in production in vacuum cleaner 1 line after the production started. To calculate number of finished goods pallet, 6000 pieces is first divided by 24 to find daily production and related result is again divided by 24 as a pallet consists of that much finished goods.

From above information, number of finished goods pallet demonstrated in table 5.5 is multiplied by three to calculate number of material pallets.

**Table 5.5:** Consumer Products Factory Material Pallets (pal/day)

| **Consumer Products Factory Material Pallets (pal/day)** | |
|---|---|
| **Production Type** | **2013** |
| VC_1 | 69 |
| VC_2 | 33 |
| PLS_SLICER | 18 |
| METAL_SLICER | 27 |
| BLENDER | 6 |
| TOTAL | 153 |

#### 5.5.1.2. Goods Receipt and Incoming Inspection Area

As it is stated by quality control for goods receipt department, 5 % of receipt goods are randomly controlled every day. According to the above table 5.5, 153 material pallets are received by warehouse and (153*5) / 100 = 8 pallets of materials are controlled daily.

#### 5.5.1.3. Incoming Inspection and Blocked Material Storage Area

According to data taken from incoming inspection, % 7 of all received materials is transported to blocked materials storage area. Therefore it can be noted that 1 pallet of all incoming materials have some quality problems and should be moved to blocked material storage area.

#### 5.5.1.4. Chemical Warehouse and Production Lines

Although some of them are common for different lines, there are 15 different kinds of chemicals which are used during production. According to a weekly observation, it has been realized that chemical materials are transported one time to each line at the beginning of each shift and therefore 2 times in a day. On the other hand, related chemicals are usually left without fully consumed at the end of the day and transported to chemical warehouse again.

### 5.5.1.5. Production Lines and Quality Control for Finished Goods

According to data taken from quality control for finished goods, % 3,5 of all finished goods are transported to quality control for finished goods area with the purpose of conducting some tests whereas rest of them are collected in finished goods collecting area. Depending on this information, number of pallets transported to finished goods controlling area and finished goods collecting are separately as follows:

**Table 5.6:** Number of pallets from production lines to quality control area each day.

| Number of pallets carried from production lines to quality control area (daily) | |
|---|---|
| **Production Type** | **2013** |
| VC_1 | 3 |
| VC_2 | 3 |
| PLS_SLICER | 1 |
| METAL_SLICER | 1 |
| BLENDER | 1 |
| TOTAL | 9 |

Sometimes the pallets are carried half completed. But it was taken as one though there needs one forklift move to carry the half pallets. In the above table 5.6, it has to be stated that VC_1 and VC_2 are exceptions. Quality control auditors stated that as VC_1 is the most recent established production line, they notice plenty of failures each day. This is the reason they aimed to control more than 3, 5 % in this line. On the other hand this will be the same for VC_2 line when it will actively start production in December.

Depending on the above explanation, number of pallets transported from production lines to finished goods collecting area is found by subtracting above numbers from total numbers of finished goods pallet and can be found in below table 5.7:

**Table 5.7:** Number of finished goods pallets transported from production lines to finished goods collecting area

| **Number of pallets carried from production lines to finished goods collection area** | |
|---|---|
| **Production Type** | **2013** |
| VC_1 | 20 |
| VC_2 | 8 |
| PLS_SLICER | 5 |
| METAL_SLICER | 8 |
| BLENDER | 1 |
| TOTAL | 46 |

#### 5.5.1.6. Production Lines and Returnable Packaging

Production manager of the factory stated their main goal as ensuring all material deliveries by using returnable packaging as it is a significant step to decrease material price. However, at this moment in time, it has not yet been possible to provide returnable packaging for all materials. According to data taken from packaging engineer of the factory, percentage of returnable packaged materials for each line can be shown in below table 5.8.

**Table 5.8:** Percentage of returnable packaged materials with respect to each production line

| **Percentage of returnable packaged materials for each production line** | |
|---|---|
| **Production Type** | **2013** |
| VC_1 | 35 |
| VC_2 | 30 ( foresight) |
| PLS_SLICER | 25 |
| METAL_SLICER | 30 |
| BLENDER | 15 |

The next step is to multiple total material pallets with these ratios to calculate number of returnable packaging pallets transported from production lines to returnable packaging area separately.

**Table 5.9:** Number of Returnable packaging pallets transported from each production line

| **Number of returnable packaging pallets carried from each line** | |
|---|---|
| **Production Type** | **2013** |
| VC_1 | 25 |
| VC_2 | 10 |
| PLS_SLICER | 5 |
| METAL_SLICER | 9 |
| BLENDER | 1 |
| TOPLAM | 50 |

#### 5.5.1.7. Quality Control for Finished Goods and Blocked Materials Storage Area

Quality control department has stated that % 42 of all controlled finished goods have some quality problems and therefore have to be carried to blocked material storage area. It has been further defined that 5 pallets of materials are controlled each day and therefore average of (5*42)/100 = 2 pallets are transported from finished goods collecting to blocked materials storage area.

#### 5.5.1.8. Finished Goods Collecting and Loading Area (Goods Receipt)

All finished goods transported from production lines to finished goods collecting area are further moved to loading area with the purpose of providing central logistic responsible to carry these materials to central logistics warehouse.  Therefore it must be stated that number of pallets transported from finished goods collecting to loading area is 46.

#### 5.5.1.9. Returnable Packaging and Loading Areas

All the packaging equipment collected in returnable packaging area are loaded to trucks in loading area and transported to related suppliers. Therefore total number of returnable packaging pallets which is 50 is also the number of transported pallets between returnable packaging and loading area.

#### 5.5.1.10. Blocked Material Storage and Production Lines

Materials which are blocked by incoming inspection and finished goods those are blocked by finished goods control department are all transported to blocked material storage area. All the finished goods blocked by audit are re-transported to production lines for rework. According to data taken from audit, usually one of the blocked finished goods pallets belongs to vacuum cleaner line as it is a rather new established line the other belongs to metal slicer line with respect to the complexity of the product. Plastic slicer and blender are the earliest products being produced and it is not so common that they notice finished goods failures in this related lines. On the other hand it is assumed that one pallet of finished goods may be blocked in VC_2 line depending on the data provided from VC_1 line.

#### 5.5.1.11. Incoming Inspection& Blocked Material Storage Area and Warehouse

In previous sections it was stated that an average of 16 pallets of materials are controlled and 1 pallet is kept under blocked. Therefore it is so obvious that this one pallet is first carried to blocked material than to loading area for conducting return to vendor procedure whereas rest of the 15 pallets are transported to warehouse and addressed as a stock for further uses.

#### 5.5.1.12. Blocked Material & Loading and Warehouse

All the blocked materials with quality control problems are transported from blocked material storage area to loading area for return to vendor as stated before. Therefore one pallet of material is transported to blocked material to loading area.

#### 5.5.1.13. Warehouse and Loading Area

Warehouse staff has some extra works to do like raw material delivery to suppliers, sending spare parts to service center or sample preparation for central development. Those kinds of materials are first transported from warehouse to loading area and loaded to trucks here from the related ramps. Warehouse responsible stated that it is not possible to define exact numbers for number of movements from warehouse to loading area. But according to the five days observation in warehouse it was determined that an average of 20 pallets of materials are loaded each day.

#### 5.5.1.14. Quality Control for Finished Goods and Production Lines

It was further stated that between the finished goods, the ones with quality control problem are blocked for loading in blocked material storage area whereas other materials without failures are transported to production lines for the purpose of completing all pallet to make them ready for transportation. It was also further stated that blocked materials with a percentage of 90 percent mostly belongs to VC_1 or MTL_Slicer lines as VC_1 is a rather new line and MTL_Slicer is a more complicated product than others. Additionally, finished goods pallets without failures are considered as one pallet as they require one movement therefore half finished goods pallets without failures are rounded up to 1 as they require 1 material movement.

**Table 5.10:** Number of daily pallets transported from quality control to production area

| Number of pallets transported from quality control to production area | |
|---|---|
| **Production Type** | **2013** |
| VC_1 | 3 |
| VC_2 | 3 |
| PLS_SLICER | 1 |
| METAL_SLICER | 1 |
| BLENDER | 1 |
| TOTAL | 9 |

### 5.5.1.15. Goods Receipt and Warehouse

It has been indicated that 153 pallets of materials are received to warehouse passing through goods receipt area. 8 of these pallets are transported to incoming inspection for quality control. Therefore rest of the 145 pallets is transported to warehouse for addressing to use in later production.

### 5.5.1.16. Goods Receipt and Chemical Warehouse

Unfortunately it was not possible to have exact number of chemical materials pallets received per day. But according to data taken from material planning engineer of the factory and warehouse responsible, average of 2 pallets of chemical materials are received each day.

All these information, calculated in above section by applying some of the assumptions are integrated and the final flow matrix is ready to be in use as an input of CRAFT which can be found in below table 5.11.

**Table 5.11:** Flow Matrix of the Factory

| **TO** | *GS* | *GS* | *PLS* | *MTL* | *BLN* | *LO* | *FG* | *RTR* | *BLK* | *INC* | *WH* | *QLY* | *GR* | *CHM* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FROM** | *40* | *20* | *SLC* | *SLC* | | | | *STR* | *MTR* | *INS* | | *CNT* | | *WH* |
| *GS 40* | - | | | | | | 20 | 25 | | | | 3 | | |
| *GS 20* | | - | | | | | 8 | 10 | | | | 3 | | |
| *PLS SLC* | | | - | | | | 5 | 85 | | | | 1 | | |
| *MTL SLC* | | | | - | | | 8 | 9 | | | | 1 | | |
| *BLN* | | | | | - | | 1 | 1 | | | | 1 | | |
| *LO* | | | | | | - | | | | | | | | |
| *FG* | | | | | | | - | | 2 | | | | 46 | |
| *RTR STR* | | | | | | | | - | | | | | 50 | |
| *BLK MTR* | 1 | 1 | | 1 | | | | | - | | | | 1 | |
| *INC INS* | | | | | | | | | | - | | | | |
| *WH* | 69 | 33 | 18 | 27 | 6 | | | | | | - | | 20 | |
| *QLY CNT* | 3 | 3 | 1 | 1 | 1 | | | | | | | - | | |
| *GR* | | | | | | | | | | 8 | 145 | | - | 2 |
| *CHM WH* | 2 | 2 | 2 | 2 | 2 | | | | | | | | | - |

### 5.5.2. Generation of Cost Matrixes

Distances between different departments have to be decreased as far as possible in order to minimize transportation costs. However it is so obvious that, decreasing some of the distances also means that increasing some others. Depending on this fact, it can be emphasized that what is so significant to make a successful layout design with less transportation cost is to decrease the distances where there is more material flow comparing to the rest. Above flow matrix shown in table 5.11 assists designer to see between which departments there is more transported materials comparing to rest. Furthermore distances of related materials also have to be demonstrated in a matrix either by using Euclidean or Rectilinear distance measure.

With the purpose of generating cost matrix, designer must define the matrix of distances between all departments those have a material movement between each other. Transport cost in unit distance can be further determined and all related distances can be multiplied with unit transportation cost to create cost matrix. Only one kind of forklift which uses electricity is in use in the factory for transporting materials. On the other hand, it is so clear that as the ratio of costs between different departments will not change when multiplying with the same unit cost value, distance matrix between different departments will be taken as the cost matrix in the study. Related results will not impact the results with respect to the fact that the proportion of transportation costs will be the same.

In current situation, the factory does not contain a well-established logistic concept which basically means that there is a lack of steady material handling system. Therefore, two different layout designs both on the basis of Rectilinear and Euclidean measure will be presented in this study. Below two different distance matrixes prepared on the basis of Euclidean and Rectilinear measures can be found. Distances are expressed in terms of meter unit in both of the tables of 5.12 and 5.13.

**Table 5.12:** Distance Matrix prepared on the basis of Rectilinear Measure

| **TO**<br>**FROM** | *GS 40* | *GS 20* | *PLS SLC* | *MTL SLC* | *BLN* | *LO* | *FG* | *RTR STR* | *BLK MTR* | *INC INS* | *WH* | *QLY CNT* | *GR* | *CHM WH* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *GS 40* | - | | | | | | 44 | 66 | | | | 77 | | |
| *GS 20* | | - | | | | | 44 | 66 | | | | 64 | | |
| *PLS SLC* | | | - | | | | 57 | 81 | | | | 76 | | |
| *MTL SLC* | | | | - | | | 15 | 38 | | | | 32 | | |
| *BLN* | | | | | - | | 60 | 51 | | | | 31 | | |
| *LO* | | | | | | - | | | | | | | | |
| *FG* | | | | | | | - | | 39 | | | | 87 | |
| *RTR STR* | | | | | | | | - | | | | | 77 | |
| *BLK MTR* | 72 | 86 | | 56 | | | | | - | | | | 58 | |
| *INC INS* | | | | | | | | | 31 | - | 59 | | | |
| *WH* | 112 | 126 | 143 | 116 | 133 | | | | | | - | | 65 | |
| *QLY CNT* | 77 | 64 | 76 | 32 | 31 | | | | | | | - | | |
| *GR* | | | | | | | | | | 43 | 65 | | - | 94 |
| *CHM WH* | 83 | 99 | 115 | 130 | 143 | | | | | | | | | - |

It was written in the manual of this software that, it is better to use rectilinear distance measure when material movements are parallel to boundaries of the facility. As previously stated there is not a clear logistic concept yet and as a result two different design alternatives both on the basis of Rectilinear and Euclidean distance measure will be presented in this study. Depending on further changes in material handling system design, one of the two alternatives can be selected.

**Table 5.13:** Distance Matrix prepared on the basis of Euclidean Measure

| **TO** / **FROM** | *GS 40* | *GS 20* | *PLS SLC* | *MTL SLC* | *BLN* | *LO* | *FG* | *RTR STR* | *BLK MTR* | *INC INS* | *WH* | *QLY CNT* | *GR* | *CHM WH* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *GS 40* | - | | | | | | 30 | 55 | | | | 58 | | |
| *GS 20* | | - | | | | | 33 | 55 | | | | 53 | | |
| *PLS SLC* | | | - | | | | 42 | 60 | | | | 53 | | |
| *MTL SLC* | | | | - | | | 15 | 27 | | | | 24 | | |
| *BLN* | | | | | - | | 30 | 38 | | | | 24 | | |
| *LO* | | | | | | - | | | | | | | | |
| *FG* | | | | | | | - | | 39 | | | | 66 | |
| *RTR STR* | | | | | | | | - | | | | | 61 | |
| *BLK MTR* | 55 | 62 | | 40 | | | | | - | | | | 44 | |
| *INC INS* | | | | | | | | | 31 | - | 59 | | | |
| *WH* | 65 | 80 | 95 | 77 | 92 | | | | | | - | | 30 | |
| *QLY CNT* | 58 | 53 | 53 | 24 | 24 | | | | | | | - | | |
| *GR* | | | | | | | | | | 43 | 65 | | - | 94 |
| *CHM WH* | 64 | 77 | 92 | 85 | 99 | | | | | | | | | - |

## 5.6. Constraints of the Model

It had better to take in to account limitations of layout add-in before introduction to the software in order to be aware of possible complexities that the user can experience. This Excel add-in can assists the designer to apply 2 different types of heuristic procedure. However it has some constraints besides various benefits in which some of them have already been mentioned in previous sections. The user should be aware of these constraints to minimize the negative effect of using this add-in. The first disadvantage of this program is that it only takes transportation cost minimization as objective function in to consideration. Although the most important factor during the process of layout design seems to be transportation cost, there can be also some other significant elements of design process that have to be taken in to consideration. Those factors apart from costs are analyzed under the heading of feasibility. For example chemical materials especially the ones with flammability property have to be kept in special warehouses dedicated to materials of this kind and chemical materials that can interact between each other have to be kept separately. Building constraints also affect the concept of feasibility. As CRAFT software designs the layout according to the areas of departments, this property may cause problems in such facilities that height has great importance. Designing layout on the basis of volume of the areas may generate better results. Another problem of CRAFT software is that while selecting the shapes of units, it generates complicated structures apart from tetragonal this is why program makes cost calculation with respect to the center of gravity of each unit. In this study, related areas will be located as in such a manner that they will be arranged as the shape of a tetragonal or quasi-tetragonal.

Additionally, CRAFT software does not consider fork-lift paths in which the related material flows take place. Those paths will be added to layout after the new layout alternatives are selected. Under all these constraints, different regions will be created and the most appropriate design on the basis of least transport cost will be determined. Apart from all these related negativities, this add-in is a beneficial tool to help designer to present locating which departments close to each other decreases the cost of transportation best.

## 6. INTRODUCTION TO FACILITY LAYOUT ADD-IN

In this study, traditional CRAFT algorithm will be used to analyze current layout and to propose new layout alternatives, as it was previously indicated. This algorithm should be installed to Excel as add-in. In the following section, the emphasize will be on the basics of facility layout add-in that implements either CRAFT or a sequential method for layout design process. Additionally how this add-in should be utilized for layout design will be explained in details.

Necessary inputs to run this add-in are the list of departments and their areas, material flows and material transportation costs between these departments and the total size of the facility. The objective function of the program is material handling cost minimization. On the other hand, it is possible to generate a solution by using one of two algorithms provided by this software in which one of them is traditional CRAFT and a second one which is established on the basis of sequencing and aims to define the optimum sequence of departments. It has to be emphasized that both of the procedures are heuristic and they do not necessarily guarantee attaining optimum solution.

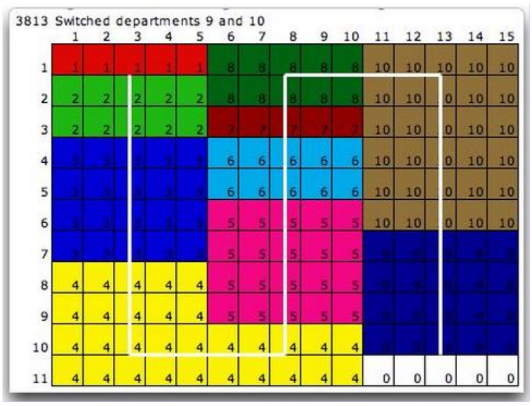


**Figure 6.1:** A graphical representation of layout

When the designer identifies all necessary inputs and run the program, a graphical representation of the layout which is especially beneficial to compare the results of possible alternatives, emerges on the screen as in above figure of 6.1. Each number written in the middle of cells demonstrates that related cell is dedicated to that department and the program aims to help designer to define best layout alternatives of 11 different departments according to above example. Each department is graphically represented with a different color to provide easiness of distinguishing between departments and the number of cells assigned to each department is representative for the size of that department. White lines represent the number of aisles in the facility in above example of 6.1. Depending on the fact that the program does not consider aisles, 5 white cells that take place at the bottom of illustrative layout are marked with number zero and remained empty. It can be seen that, total plant size of above example is pictured with 15 cells long and 11 cells wide.

### 6.1. New Layout Generation Procedure

After the installation of CRAFT add-in, a new layout is created as a new project. As soon as new layout option from facility layout menu is selected, the user meets with the dialog box shown below.

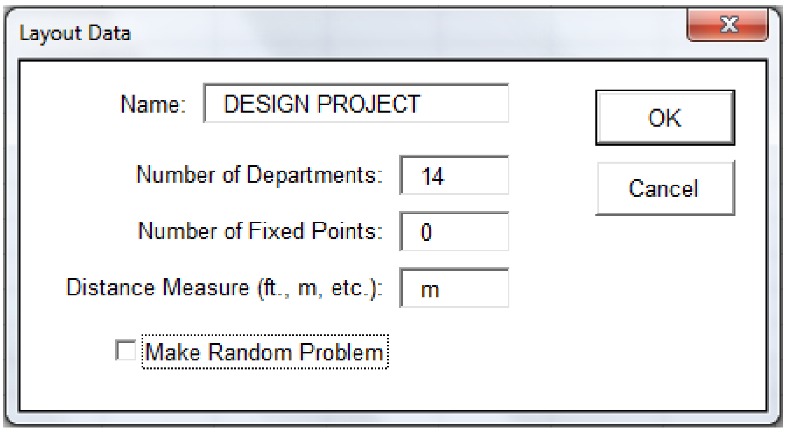


**Figure 6.2:** Dialog box to define the basics of the project

Designer has to identify the name of the project, number of departments, number of fixed points and distance measure to go through another phase in the project. Additionally, if the user would also like to see random interdepartmental flows, Make Random Problem box also has to be checked. The name of the study in this study was defined as "DESIGN PROJECT" and will be filled as a default till the end of the design process. Departments and their characteristics of being variable or fixed were introduced in previous section of generating flow and cost matrixes.. As can be remembered, number of departments is 14 in which 3 of them are determined as variable whereas 11 of them are defined as fixed.

### Layout Data

| | |
|---|---|
| Problem Name: | DESIGN PROJECT |
| Number Depts.: | 14 |
| Fixed Points: | 0 |
| Dimension: | m |

Define Facility

### Facility Information

| | | |
|---|---|---|
| Scale-m/unit | 1,5 | Cells |
| Length-m | 112,5 | 75 |
| Width-m | 75 | 50 |
| Area-sq.m | 8437,5 | 3750 |

### Department Information

| | Name | F/V | Area | Cells |
|---|---|---|---|---|
| Dept. 1 | GS40 | V | 384 | 171 |
| Dept. 2 | GS20 | V | 384 | 171 |
| Dept. 3 | PS SLICER | V | 384 | 171 |
| Dept. 4 | METAL SLICER | V | 384 | 171 |
| Dept. 5 | BLENDER | V | 384 | 171 |
| Dept. 6 | LO | V | 2443 | 1086 |
| Dept. 7 | FINISHED GOODS | V | 384 | 171 |
| Dept. 8 | RETURNABLE STR. | V | 282 | 126 |
| Dept. 9 | BLOCKED MAT. | V | 219 | 98 |
| Dept. 10 | INCOMING INS. | V | 232 | 104 |
| Dept. 11 | WAREHOUSE | F | 1901 | 845 |
| Dept. 12 | QUALITY CONTROL | V | 348 | 155 |
| Dept. 13 | GOOD RECEIPT | F | 411 | 183 |
| Dept. 14 | CHEMICAL WH. | F | 263 | 117 |

**Figure 6.3:** Layout Worksheet Data to define facility and department information

Another important issue is about fixed points which are basically defined whether there is a departmental flow passing through or from fixed points. For example, loading or shipping docks can be taken as fixed points whereas in this study there is no need to use fixed point logic as loading ramps were accepted as goods receipt department and fixed as a whole as it is the same as warehouse and chemical warehouse.

Layout data worksheet seen above is generated following that the user presses OK button in above dialog box 6.2.

Necessary information which has to be defined by the user in this worksheet consists of two main categories of necessary data about facility and department.  The user should input facility length and width with the same distance measure which has already been defined in previous dialog box.  Scale factor is required to convert distance measure into cells measure by taking the limitations of the program in to account. It has to be stated that, facility dimensions can be defined with maximal 50 cells wide and 100 cells long. A scale factor of greater than one has to be used to convert distance measure in to cell measure if one of the dimensions of the plant is greater than the above limitations.  The user can also identify a scale factor of greater than 1 when there is a need to reduce solution times.

According to the data taken from the cad drawings of the current situation, it has been found that the factory is 112, 5 meters long and 75 meters wide.  However as further explained it is only possible to work with a factory dimension of 50 cells long and 100 cells wide, maximal 5000 cells in total.  Therefore it is obligatory to use a scale factor of more than 1 to make it possible to run the program.  In this study a scale factor of 1, 5 is selected which makes a total number of 3750 cells requirement.

It has to be highlighted that yellow cells should not be changed with respect to the fact that they include either formulas or quantities fixed by the program whereas data cells with white background can be changed.  It can also be seen that the name of the project that was defined in earlier section also appears in this worksheet as "DESIGN

PROJECT" and should not also be changed. Moreover, number of departments entered at the beginning of the project is also fixed by the program as 14.

After the information about facility is defined, the user also has to fill necessary information about departments which starts from the 16th row of the worksheet. Column B represents the name of the departments whereas the letters of F (fixed) or V (variable) is written in column C. The meaning of the letter F and V is so clear that this selection depends on whether the location or sequence of department is fixed or variable during the process of searching optimum layout alternative. The user should also enter the area of related departments in column D which was calculated with the same distance measure which can be in square meters according to current example. On the other hand column E shows the cell measure of related areas of departments. A scale factor is required to convert areas of each department to cell measures. Departmental areas become same with cell measures in column E providing that a scale factor of 1 is used.

The user has to describe each department whether with an F or a V. This add-in allows the user to generate different layout alternatives based on two different methodologies which are Sequence or Traditional solution methodologies. If a department is labeled with letter F, it means that this department is fixed in sequence or location with respect to user's solution method of preferences. F labeled departments keeps their index of sequencing in sequence solution method, whereas they retain their locations in traditional CRAFT method. The user should define the characteristics of each department in this worksheet as fixed or variable as the program needs this information to generate new layout alternative. Additionally, it has to be added that when V labeled variable departments have different areas, their locations can be changed for different sequences if Sequence Solution Methodology is preferred.

**Table 6.1:** Flow Matrix

| Flow Matrix FROM/TO | GS40 | GS20 | PS SLICER | METAL SLICER | BLENDER | LO | FINISHED GOODS | RETURNABLE STR. | BLOCKED MAT. | INCOMING INS. | WAREHOUSE | QUALITY CONTROL | GOOD RECEIPT | CHEMICAL WH. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GS40 | - | | | | | | 20 | 25 | | | | 3 | | |
| GS20 | | - | | | | | 8 | 10 | | | | 3 | | |
| PS SLICER | | | - | | | | 5 | 5 | | | | 1 | | |
| METAL SLICER | | | | - | | | 8 | 9 | | | | 1 | | |
| BLENDER | | | | | - | | 1 | 1 | | | | 1 | | |
| LO | | | | | | - | | | | | | | | |
| FINISHED GOODS | | | | | | | - | | 2 | | | | 46 | |
| RETURNABLE STR. | | | | | | | | - | | | | | 50 | |
| BLOCKED MAT. | 1 | 1 | | 1 | | | | | - | | | | 1 | |
| INCOMING INS. | | | | | | | | | 1 | - | 15 | | | |
| WAREHOUSE | 69 | 33 | 18 | 27 | 6 | | | | | | - | | 20 | |
| QUALITY CONTROL | 3 | 3 | 1 | 1 | 1 | | | | | | | - | | |
| GOOD RECEIPT | | | | | | | | | | 8 | 145 | | - | 2 |
| CHEMICAL WH. | 2 | 2 | 2 | 2 | 2 | | | | | | | | | - |

Above flow matrix in table 6.1 and below cost matrix in table 6.2 were filled according to the data taken from previous section of generating flow and cost matrixes. According to the user information about number of departments in previous section, 14 in this case, program prepares two empty matrixes in order to demonstrate material flows and the cost of material transportations between these departments. The user should fill necessary data in this field as they were entered in above table of 6.1 and below tables of 6.2 and 6.3.

Flow Matrix, "*From to Matrix"* in other words, has already been filled with necessary data as can be seen in table 6.1. When a cell of (i, j) is filled with a number, it means that there is that much flow between department i to j. To help how to interpret this matrix, it can be said that there are 2 units of transport from chemical warehouse (department 14) to Vacuum Cleaner_1 line (department 1) with respect to data taken from figure 6.1.  According to above flow matrix, it is possible to say that the largest amount of transportation is not only between goods receipt area and warehouse but also between warehouse and production lines.

**Table 6.2:** Cost Matrix (Rectilinear)

| Cost Matrix FROM/TO | GS40 | GS20 | PS SLICER | METAL SLICER | BLENDER | LO | FINISHED GOODS | RETURNABLE STR. | BLOCKED MAT. | INCOMING INS. | WAREHOUSE | QUALITY CONTROL | GOOD RECEIPT | CHEMICAL WH. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GS40 | - | | | | | | 44 | 66 | | | | 77 | | |
| GS20 | | - | | | | | 44 | 66 | | | | 64 | | |
| PS SLICER | | | - | | | | 57 | 81 | | | | 76 | | |
| METAL SLICER | | | | - | | | 15 | 38 | | | | 32 | | |
| BLENDER | | | | | - | | 60 | 51 | | | | 31 | | |
| LO | | | | | | - | | | | | | | | |
| FINISHED GOODS | | | | | | | - | | 39 | | | | 87 | |
| RETURNABLE STR. | | | | | | | | - | | | | | 77 | |
| BLOCKED MAT. | 72 | 86 | | 56 | | | | | - | | | | 58 | |
| INCOMING INS. | | | | | | | | | 31 | - | 59 | | | |
| WAREHOUSE | 112 | 126 | 143 | 116 | 133 | | | | | | - | | 65 | |
| QUALITY CONTROL | 77 | 64 | 76 | 32 | 31 | | | | | | | - | | |
| GOOD RECEIPT | | | | | | | | | | 43 | 65 | | - | 94 |
| CHEMICAL WH. | 83 | 99 | 115 | 130 | 143 | | | | | | | | | - |

**Table 6.3:** Cost Matrix (Euclidean)

| Cost Matrix FROM/TO | GS40 | GS20 | PS SLICER | METAL SLICER | BLENDER | LO | FINISHED GOODS | RETURNABLE STR. | BLOCKED MAT. | INCOMING INS. | WAREHOUSE | QUALITY CONTROL | GOOD RECEIPT | CHEMICAL WH. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GS40 | - | | | | | | 30 | 53 | | | | 58 | | |
| GS20 | | - | | | | | 33 | 55 | | | | 53 | | |
| PS SLICER | | | - | | | | 42 | 60 | | | | 53 | | |
| METAL SLICER | | | | - | | | 15 | 27 | | | | 24 | | |
| BLENDER | | | | | - | | 30 | 38 | | | | 24 | | |
| LO | | | | | | - | | | | | | | | |
| FINISHED GOODS | | | | | | | - | | 29 | | | | 66 | |
| RETURNABLE STR. | | | | | | | | - | | | | | 61 | |
| BLOCKED MAT. | 55 | 62 | | 40 | | | | | - | | | | 44 | |
| INCOMING INS. | | | | | | | | | 17 | - | 41 | | | |
| WAREHOUSE | 65 | 80 | 95 | 77 | 92 | | | | | | - | | 30 | |
| QUALITY CONTROL | 58 | 53 | 53 | 24 | 24 | | | | | | | - | | |
| GOOD RECEIPT | | | | | | | | | | 27 | 30 | | - | 93 |
| CHEMICAL WH. | 64 | 77 | 92 | 85 | 99 | | | | | | | | | - |

As further explained, material handling costs between different departments also have to be defined to make a comparison between different alternatives. This matrix is unique for different facilities depending on the fact that lot sizes, material handling equipment and most other factors change from facility to facility. In this study, distance matrix between departments is considered as cost matrix with respect to the fact that multiplying interdepartmental distances with unit transportation costs will not make a difference in total. It has to be stated that the facility does not have clear a logistic concept yet. Therefore two different layout alternatives which were generated on the basis of Rectilinear and Euclidean distance measure will be presented in following sections. This is basically the reason of preparing two different flow matrixes on the basis of both Rectilinear and Euclidean distance measure.

When all of the above necessary data is filled, a second worksheet with an actual image of the facility is generated following that the user presses the red button of "DEFINE FACILITY" which also takes place at the top of the page.

## 6.2. Definition of Facility

Dialog Box shown below appears following that the user presses the button on Layout Data Worksheet as expressed in above section. Different kinds of options in which the user has to select among them exist in this box.

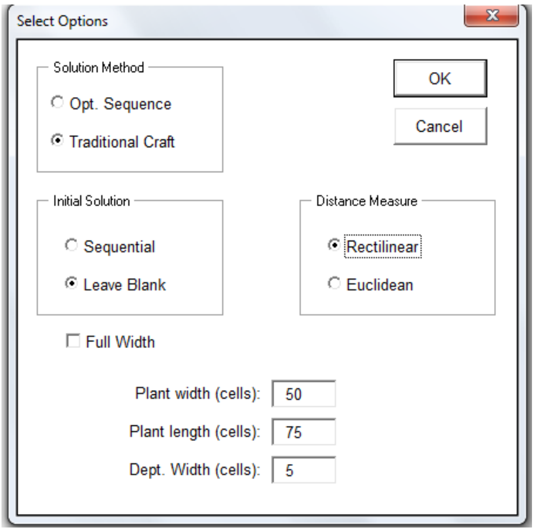


**Figure 6.4:** Dialog Box to select solution methodology

As can also be noticed from dialog box above and as it was already mentioned, two different solution options of “Optimum Sequence” and “Traditional Craft” are provided with this add-in. Department width and related sequence which are necessary to locate the departments through the aisles of the facility are the determinatives of sequential layout. At each step, optimum sequence method calculates the cost changes of all possible switches of two departments in order to acquire the most efficient pair. The method repeats itself in such a way that two departments are switched with respect to sequence until no switching procedure provides a reduction in cost. In this study “Traditional Craft” algorithm will be selected instead of “Optimum Sequence” algorithm with respect to the fact that Traditional Craft has an important option of “*Leave Blank*”. The user can define initial solution by selecting one of the related options of “Leave Blank” or “Sequential”. If "*Leave Blank*" option is selected, layout is initially left as blank and the user manually pictures the location of departments. As the factory has an initial layout design, using this option is beneficial to draw and analyze the cost of current situation. Depending on the fact that, one of the main objectives of this project is to analyze current situation; “Leave Blank” option will be selected as already explained. On the other hand, it has to be reminded that three departments of Chemical Warehouse, Warehouse and Goods Receipt are fixed and their locations cannot be changed as either ramps or racks have been already established. This is another reason which makes it easier and more beneficial to choose “Leave Blank” option to obtain initial solution. If the user selects this option to generate initial solution, a blank layout ready to be filled manually by the user is created by the program. Facility length and width have the same size of cells, previously defined by the user. Blank layout represents a similar shape as possible with the actual facility. Below blank layout in figure 6.5 is presented as an example. However, Appendix C1 is representative for actual blank layout which is used in this project. In the actual blank layout, length of the facility is represented with 75 cells whereas 50 cells are used to define the width of the facility.

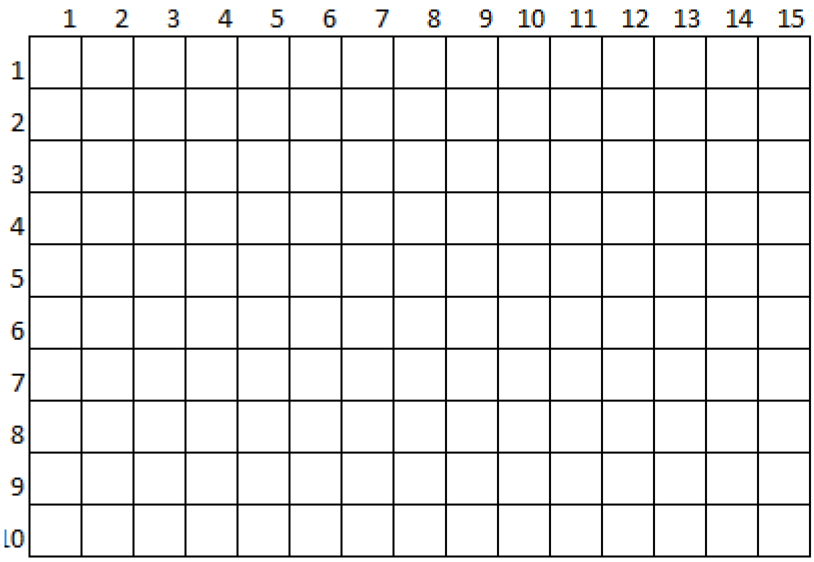


**Figure 6.5:** A blank Layout ready to be filled with departmental information

Initial layout is created by placing numbers on it. After marking a cell with a number, the user should press “Evaluate” button to assign required number of cells to a department. The same procedure has to be repeated at each step of placing a new department in initial layout. All departments are demonstrated with a different color when the last department is defined. Only defined cells in initial layout can be used in Craft method. Some cells can be left simply leaving them as empty. But in this case, they are never used by the program. On the other hand, it has to be added that software does not run unless each department consists of at least as much as cells determined in layout worksheet data in figure 6.3.

Another option which has to be defined by the user is distance measure. It defines the interval between different departments which is calculated by taking the distance between their corresponding centroids. It has been stated in user manual that it is more logical to use a rectilinear measure when a parallel material movement to the length and width boundaries of plant exists whereas the Euclidean measure should be better in use when the material movement in the facility generally takes place through straight lines between the related two centroids. Depending on the fact that material movement strategy in the facility is not clear yet, two different design alternatives will be generated either by selecting "Euclidean" or "Rectilinear" distance measures.

Additionally; necessary information about facility dimensions that can be seen at the bottom of the dialog box are automatically filled as the designer has already entered facility length, width and department width data. Department width is a parameter which is required to determine aisle layout. Department width shows the maximum number of cells required to define each single department from right to left. During the procedure of demonstrating each department in initial layout, if more than 5 cells are required to define a department, first 5 cells are filled and then rest of the cells are demonstrated in underlying row and this procedure repeats till all the cells of related department is demonstrated. However, department width does not have an effect on the solution when “Leave Blank” option is selected. In this study initial layout was generated with respect to the current situation of the facility according to the data taken from related Cad Drawings presented in Appendix B. Furthermore, related Initial Layout which was created by using “Leave Blank” option can also be found in Appendix C2. After the initial layout is generated according to the rules mentioned above, the user should push “EVALUATE” button to run the program. The following section is dedicated to CRAFT solutions.

### 6.3. Craft Solutions

Working with facility layout add-in can be analyzed under three main headings of new layout generation as a new project, definition of facility on the program and interpreting program solutions to adapt new layout. After first two steps are completed, the final step is to run the program and to interpret the results. There are two sub-headings of this part as two different layout designs will be suggested on the basis of different distance measures of rectilinear and Euclidean. In the following section, initially the results for Rectilinear distance measure, than Euclidean distance measure will be presented.

### 6.3.1. Rectilinear Distance Measure

Distance measure option is selected by using dialog box in figure 6.4. Rectilinear distance measure is selected in this dialog box. After other selections are made and a model of actual layout is generated by using “Leave Blank" option, the user should press” EVALUATE" button and below facility layout worksheet that represents initial conditions of layout appears on the screen. The objective of the program is to decrease this initial cost of "2109792" by switching the locations of different departments.

Facility Layout

| | | | |
|---|---|---|---|
| Problem Name: | DESIGN PROJECT | Method: | Traditional |
| Number Depts.: | 14 | Layout: | Blank |
| Length(cells): | 75 | Fill Departments: | No |
| Width(cells): | 50 | Measure: | Rectilinear |
| Area (cells): | 3750 | Number Aisles: | 10 |
| Cost: | 2109792 | Dept. Width: | 5 |

| Department | Color | Area-required | Area-defined | x-centroid | y-centroid | Sequence |
|---|---|---|---|---|---|---|
| GS40 | 1 | 171 | 171 | 22,5 | 9,5 | 1 |
| GS20 | 2 | 171 | 171 | 13,5 | 9,5 | 2 |
| PS SLICER | 3 | 171 | 171 | 4,5 | 9,5 | 3 |
| METAL SLICER | 4 | 171 | 171 | 13,5 | 28,5 | 4 |
| BLENDER | 5 | 171 | 171 | 4,5 | 28,5 | 5 |
| LO | 6 | 1086 | 1086 | 39,570904 | 21,722836 | 6 |
| FINISHED GOODS | 7 | 171 | 171 | 22,5 | 28,5 | 7 |
| RETURNABLE STR. | 8 | 126 | 126 | 18,666666 | 43,166668 | 8 |
| BLOCKED MAT. | 9 | 98 | 98 | 28 | 46,5 | 9 |
| INCOMING INS. | 10 | 104 | 108 | 43,194443 | 46,805557 | 10 |
| WAREHOUSE | 11 | 845 | 849 | 63,524734 | 23,542402 | 11 |
| QUALITY CONTROL | 12 | 155 | 156 | 6,5 | 44 | 12 |
| GOOD RECEIPT | 13 | 183 | 184 | 63,5 | 46 | 13 |
| CHEMICAL WH. | 14 | 117 | 117 | 63,320515 | 2,5512822 | 14 |

**Figure 6.6:** Facility Initial Layout Data Worksheet (Rectilinear)

This excel worksheet in figure 6.6., consists of departmental information which are name of the departments and with which colors and numbers are used to demonstrate related departments.  Furthermore; required area for that department and how many cells are used to determine that department can be found in column C and D of this layout data worksheet.  For example red color cells in which number 1 is written inside demonstrates department of GS40. At least 171 cells should be used and were used to define this department.  On the other hand; values on E and F columns demonstrate the X-Y centroids of each related department which can be verified by using the initial layout figure demonstrated in Appendix C2.  Furthermore it has to be stated that the program cannot be run unless area-defined is bigger than or at least equal to area-required.

Additionally, it has to be added that yellow colored cells that take place at the top of this worksheet are filled automatically on the basis of data provided by the user in previous sections. Related data consist of name of the project, number of cells used to demonstrate the length and width of the facility and also total number of cells used to demonstrate whole facility which is also the same as the area of it which is calculated on the basis of cell measure and found by multiplying length and width of facility in cells measure. Most significant information that can be attained from this layout worksheet is cost of transportation for initial layout which is 2109792. The objective of designer should be decreasing this value by letting the program run to display best possible option by making iterations and further possible switching operations of the user between some departments when a potential cost of decrease is detected in layout design.  With respect to figure 6.6., it also has to be stated that the method to generate initial layout is "leave blank" and Rectilinear was selected as distance measure option.

After the necessary condition of area required should be at least equal to area defined can be provided and the program is run to show the user results for initial layout, following option dialog box appears on the screen following that the user pushes “SOLVE" button.

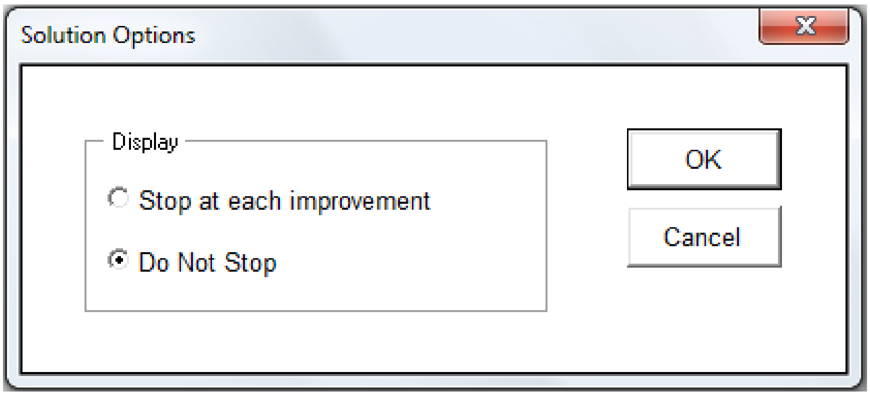


**Figure 6.7:** Solution Options Dialog Box

As can be seen in this dialog box, the program presents two different options of "stop at each improvement" and "do not stop". The program aims to find best layout alternative by consecutively switching locations of selected two departments. When first option of "stop at each improvement" is selected, designer can see each switching operations step by step whereas "do not stop" option directly presents the result without demonstrating each single switching operation between different departments. However, in both cases the user can see all switching operations when the results are displayed. After one of the above options is selected the program runs and the user can see the layout alternative proposed by the program.

It was further stated that two different design alternatives will be generated by the assistance of this computer aided layout design tool. The best layout alternatives generated by the program on the basis of rectilinear and euclidean distance measures can be found respectively in Appendix C3 and C4 . The user can also display the summary of results in the following layout worksheet.

## Facility Layout

| | | | | |
|---|---|---|---|---|
| Problem Name: | DESIGN PROJECT | | Method: | Traditional |
| Number Depts.: | 14 | | Layout: | Blank |
| Length(cells): | 75 | | Fill Departments: | No |
| Width(cells): | 50 | | Measure: | Rectilinear |
| Area (cells): | 3750 | | Number Aisles: | 10 |
| Cost: | 1275842 | | Dept. Width: | 5 |

| Department | Color | Area-required | Area-defined | x-centroid | y-centroid | Sequence |
|---|---|---|---|---|---|---|
| GS40 | 1 | 171 | 171 | 39,30117 | 26,347954 | 1 |
| GS20 | 2 | 171 | 171 | 39,394737 | 33,184212 | 2 |
| PS SLICER | 3 | 171 | 171 | 40,52924 | 12,47076 | 3 |
| METAL SLICER | 4 | 171 | 171 | 48,19006 | 10,98538 | 4 |
| BLENDER | 5 | 171 | 171 | 22,5 | 28,5 | 5 |
| LO | 6 | 1086 | 1086 | 12,12431 | 20,62431 | 6 |
| FINISHED GOODS | 7 | 171 | 171 | 43,763157 | 45,061405 | 7 |
| RETURNABLE STR. | 8 | 126 | 126 | 37,253967 | 39,968254 | 8 |
| BLOCKED MAT. | 9 | 98 | 98 | 17,091837 | 43,897961 | 9 |
| INCOMING INS. | 10 | 104 | 108 | 26,064816 | 44,916668 | 10 |
| WAREHOUSE | 11 | 845 | 849 | 63,524734 | 23,542402 | 11 |
| QUALITY CONTROL | 12 | 155 | 156 | 33,910255 | 10,532051 | 12 |
| GOOD RECEIPT | 13 | 183 | 184 | 63,5 | 46 | 13 |
| CHEMICAL WH. | 14 | 117 | 117 | 63,320515 | 2,5512822 | 14 |

**Figure 6.8:** Facility Layout Data Worksheet for first Alternative (Rectilinear Distance Measure)

The facility layout data worksheet given in figure 6.8 represents all necessary information about final layout design. Additionally, this worksheet also represents the x-centroid and y-centroid values of the final proposed layout alternative. Since optimum sequence method is not selected, the sequence of the departments remains the same with the number of departments.

| | | | | | | |
|---|---|---|---|---|---|---|
| Init. Cost | 2109792 | | | | | |
| | | Iterations: | 14 | | | |
| Index | Init. Seq. | Iter. | Type | Action | Cost | |
| 1 | 1 | 1 | Switch: | 6 and 1 | 1973247,25 | |
| 2 | 2 | 2 | Switch: | 6 and 2 | 1837765,125 | |
| 3 | 3 | 3 | Switch: | 6 and 3 | 1707907,875 | |
| 4 | 4 | 4 | Switch: | 1 and 7 | 1626265 | |
| 5 | 5 | 5 | Switch: | 1 and 3 | 1551121,75 | |
| 6 | 6 | 6 | Switch: | 8 and 9 | 1503371,5 | |
| 7 | 7 | 7 | Switch: | 8 and 10 | 1460137,375 | |
| 8 | 8 | 8 | Switch: | 6 and 5 | 1416058,375 | |
| 9 | 9 | 9 | Switch: | 4 and 5 | 1355418,75 | |
| 10 | 10 | 10 | Switch: | 6 and 12 | 1329621,75 | |
| 11 | 11 | 11 | Switch: | 7 and 8 | 1324421 | |
| 12 | 12 | 12 | Switch: | 6 and 5 | 1300291 | |
| 13 | 13 | 13 | Switch: | 5 and 12 | 1295808,875 | |
| 14 | 14 | 14 | Switch: | 3 and 5 | 1275841,625 | |

**Figure 6.9:** All Iterations applied by CRAFT (RECTILINEAR)

It can be seen from data above in figure 6.9; best alternative proposed by CRAFT is attained after 14 different iterations. Each switching operation and transportation cost attained after the related iteration is conducted was also displayed in this figure. It can be seen that, transportation cost decreases following the related switching operation of two different departments. On the other hand, it has to be emphasized that; initial sequence column is the same with the first sequence as sequential method was not selected to generate initial layout. Another important thing to pay attention is that, final transportation cost is 1275842 money units which were 2109792 money units in initial layout as can be noticed from figure 6.6 of facility Initial Layout Data Worksheet. Following facility layout data sheet of second alternative which was presented on the basis of Euclidean measure can also be found in below figure 6.10.

### 6.3.2 Solution based on Euclidean Distance Measure

Within the concept of this study, another layout alternative will be generated by selecting Euclidean distance measure. It has to be stated that new layout generation section is the same both for Rectilinear and Euclidean distance measures. However, distance matrix in table 6.3 has to be used instead of distance matrix in table 6.2 when Euclidean distance matrix option will be selected by using dialog box in figure 6.4.

Facility Layout

| | | | |
|---|---|---|---|
| Problem Name: | DESIGN PROJECT | Method: | Traditional |
| Number Depts.: | 14 | Layout: | Blank |
| Length(cells): | 75 | Fill Departments: | No |
| Width(cells): | 50 | Measure: | Euclidean |
| Area (cells): | 3750 | Number Aisles: | 10 |
| Cost: | 1175042 | Dept. Width: | 5 |

| Department | Color | Area-required | Area-defined | x-centroid | y-centroid | Sequence |
|---|---|---|---|---|---|---|
| GS40 | 1 | 171 | 171 | 22,5 | 9,5 | 1 |
| GS20 | 2 | 171 | 171 | 13,5 | 9,5 | 2 |
| PS SLICER | 3 | 171 | 171 | 4,5 | 9,5 | 3 |
| METAL SLICER | 4 | 171 | 171 | 13,5 | 28,5 | 4 |
| BLENDER | 5 | 171 | 171 | 4,5 | 28,5 | 5 |
| LO | 6 | 1086 | 1086 | 39,570904 | 21,722836 | 6 |
| FINISHED GOODS | 7 | 171 | 171 | 22,5 | 28,5 | 7 |
| RETURNABLE STR. | 8 | 126 | 126 | 18,666666 | 43,166668 | 8 |
| BLOCKED MAT. | 9 | 98 | 98 | 28 | 46,5 | 9 |
| INCOMING INS. | 10 | 104 | 108 | 43,194443 | 46,805557 | 10 |
| WAREHOUSE | 11 | 845 | 849 | 63,524734 | 23,542402 | 11 |
| QUALITY CONTROL | 12 | 155 | 156 | 6,5 | 44 | 12 |
| GOOD RECEIPT | 13 | 183 | 184 | 63,5 | 46 | 13 |
| CHEMICAL WH. | 14 | 117 | 117 | 63,320515 | 2,5512822 | 14 |

**Figure 6.10:** Facility Initial Layout Data Worksheet (Euclidean)

Necessary information about initial layout which was previously generated by using “Leave Blank” option can be found in above figure of 6.10. Figure 6.10, 6.11 and 6.12 can be interpreted by using the information provided in section 6.3.1 which is rectilinear distance measure. It can be realized that initial cost is 1175042 when Euclidean distance matrix is selected and additionally this cost is less than initial cost of the current layout when rectilinear distance measure is used.

Facility Layout

| | | | |
|---|---|---|---|
| Problem Name: | DESIGN PROJECT | Method: | Traditional |
| Number Depts.: | 14 | Layout: | Blank |
| Length(cells): | 75 | Fill Departments: | No |
| Width(cells): | 50 | Measure: | Euclidean |
| Area (cells): | 3750 | Number Aisles: | 10 |
| Cost: | 685713 | Dept. Width: | 5 |

| Department | Color | Area-required | Area-defined | x-centroid | y-centroid | Sequence |
|---|---|---|---|---|---|---|
| GS40 | 1 | 171 | 171 | 39,394737 | 33,184212 | 1 |
| GS20 | 2 | 171 | 171 | 39,30117 | 26,347954 | 2 |
| PS SLICER | 3 | 171 | 171 | 40,774853 | 11,821637 | 3 |
| METAL SLICER | 4 | 171 | 171 | 48,19006 | 10,98538 | 4 |
| BLENDER | 5 | 171 | 171 | 33,102341 | 10,388889 | 5 |
| LO | 6 | 1086 | 1086 | 11,129834 | 23,570902 | 6 |
| FINISHED GOODS | 7 | 171 | 171 | 43,763157 | 45,061405 | 7 |
| RETURNABLE STR. | 8 | 126 | 126 | 37,253967 | 39,968254 | 8 |
| BLOCKED MAT. | 9 | 98 | 98 | 22,459183 | 32,551022 | 9 |
| INCOMING INS. | 10 | 104 | 108 | 26,064816 | 44,916668 | 10 |
| WAREHOUSE | 11 | 845 | 849 | 63,524734 | 23,542402 | 11 |
| QUALITY CONTROL | 12 | 155 | 156 | 25,570513 | 17,711538 | 12 |
| GOOD RECEIPT | 13 | 183 | 184 | 63,5 | 46 | 13 |
| CHEMICAL WH. | 14 | 117 | 117 | 63,320515 | 2,5512822 | 14 |

**Figure 6.11:** Facility Layout Data Worksheet for second Alternative (Euclidean Distance Measure)

According to above layout worksheet, it can be seen that material handling cost is decreased to 685713 money units and it can be further noticed from figure 6.12, this computer aided layout design software has made 19 different iterations to attain the best layout solution with minimum material handling cost.

Init. Cost 1175042,375

Iterations: 19

| Index | Init. Seq. |
|---|---|
| 1 | 1 |
| 2 | 2 |
| 3 | 3 |
| 4 | 4 |
| 5 | 5 |
| 6 | 6 |
| 7 | 7 |
| 8 | 8 |
| 9 | 9 |
| 10 | 10 |
| 11 | 11 |
| 12 | 12 |
| 13 | 13 |
| 14 | 14 |

| Iter. | Type | Action | Cost |
|---|---|---|---|
| 1 | Switch: | 6 and 1 | 1091185,375 |
| 2 | Switch: | 6 and 2 | 1012293,125 |
| 3 | Switch: | 6 and 3 | 940940,5 |
| 4 | Switch: | 8 and 9 | 903050,375 |
| 5 | Switch: | 8 and 10 | 860693,8125 |
| 6 | Switch: | 6 and 4 | 796993,9375 |
| 7 | Switch: | 7 and 10 | 775968,25 |
| 8 | Switch: | 6 and 5 | 750972,625 |
| 9 | Switch: | 12 and 9 | 747984,375 |
| 10 | Switch: | 2 and 7 | 744292,25 |
| 11 | Switch: | 2 and 5 | 733438,5 |
| 12 | Switch: | 2 and 3 | 724776,375 |
| 13 | Switch: | 1 and 7 | 716170,375 |
| 14 | Switch: | 7 and 8 | 710269,0625 |
| 15 | Switch: | 6 and 12 | 699491,625 |
| 16 | Switch: | 5 and 10 | 697266,125 |
| 17 | Switch: | 6 and 9 | 693943,8125 |
| 18 | Switch: | 5 and 9 | 689378,6875 |
| 19 | Switch: | 5 and 12 | 685713,125 |

**Figure 6.12:** All Iterations applied by CRAFT (Euclidean Distance Measure)

New layout alternatives on the basis of Rectilinear and Euclidean distance measures consecutively are drawn by using a CAD program, according to results of CRAFT solutions which are presented as appendix C3 and C4. Additionally, related Cad drawings which are generated according to the results of Craft solutions can be found as appendix D1 and D2.

### 6.4. Results

Apart from initial layout, two different design alternatives which were generated by selecting Rectilinear and Euclidean distance measure consecutively are presented. Depending on the results of the CRAFT, two different layout alternatives were drawn by the help of CAD programs and related results can be found in appendix section of the thesis. Following important points and results have to be kept in mind if this add-in is preferred to solve facility layout design problem.

* This add-in for facility layout design provides two different algorithms as traditional CRAFT and optimum sequence to find the best layout alternatives. It has to be pointed out that both of the procedures are heuristic which does not necessarily provide optimum solution.

* Objective function of the program is material handling cost minimization which can be considered as a disadvantage depending on the fact that layout design is a complicated task to achieve with many different constraints.

* Apart from all these related negativities, this add-in is a beneficial tool to help designer to present locating which departments close to each other decreases the cost of transportation more.

* Initial layout can be generated by using one of the algorithms as sequential or leave blank. Leave blank option is only available with traditional CRAFT.

* The maximum dimensions of a facility can be maximum 50 cells wide and 100 cells long to use this program. When factory dimensions are more than above values, a scale factor more than one has to be used in a way that maximum values will be achieved. A scale factor of more than one also decreases solution times.

* It has to be pointed out that it provides better results to select Rectilinear distance measure when material movements are parallel to the boundaries of the facility.

* Selecting Euclidean distance measure results in less transportation costs as the distance between related departments are less in Euclidean distance measure comparing to Rectilinear distance measure.

* Departments can be defined as "fixed" or “variable” in traditional CRAFT which is really helpful when there is a department that has to be fixed in location.

* As they are either include formulas or quantities fixed by the program, yellow cells should not be changed.

* The user can also make pair-wise location change between some of the departments by using SWITCH button.

* Additionally CHANGE button can be used to change some of the parameters defined by the user in previous steps.

# 7. FACILITY LOCATION SELECTION APPLICATION

Two main subjects which were aimed to be considered related with the concept of this thesis are; facility layout design and facility location selection problems. In the first part of the study an elaborate literature review about these two subjects were presented. Second part is dedicated to application section of the thesis in which selected methodologies are applied to solve related problems consecutively. In previous section CRAFT methodology was applied to design a new layout with the aim of ensuring minimum transportation cost. In this second step of application facility location selection problem will be resulted by applying fuzzy AHP and TOPSIS methods.

As previously indicated; facility location selection is a strategically important multi-criteria decision making problem. Literature review about facility location selection problems shows that conventional methods are not adequate to overcome the imprecise nature of linguistic assessment this is why fuzzy multi-criteria decision-making methods are suggested in a wide range. In this section of the study, fuzzy analytic hierarchy process (AHP) and fuzzy technique for order preference by similarity to ideal solution (TOPSIS) methods will be applied for facility location selection problem.

In the following section, first of all problem will be defined. Then, necessary information about fuzzy sets theory will be presented. Fuzzy TOPSIS and AHP methods will be later explained step by step and these two methods will be applied consecutively to facility location selection problem. The results of applied methodologies will be represented and later will be compared. The similarities and differences of two different methods will also be further discussed.

## 7.1. Problem Definition

The company in which this study is conducted has five other factories in one facility. Production in all of these 6 factories including consumer products factory that layout design process is conducted, basically only consists of assembly lines in which parts are supplied from selected vendors and assembled inside the factory. There is a possibility of establishing a new plastic injection factory to manufacture some of the selected plastic parts as in-house production especially the ones that are expensive and the others those have frequent quality problems. It has to be emphasized that various plastic parts with many different sizes are required to produce any kind of white goods. Establishing a plastic factory regarded as a necessary decision not only for financial point of view but also for increasing know-how and not to be behind competitors technically.

The aim of this section is to show decision making steps of location selection. In order to ensure these very first steps, selected methodologies will be applied. First of all decision makers which are all now work as an engineer in this company in different positions will be selected and in the next step first criterion and then alternatives with respect to these criterion will be determined in which both of these steps are necessary to apply fuzzy TOPSIS and AHP methods. After all the required steps of selected methodologies are completed, alternative in the first rank will be selected as the most suitable alternative among others.

## 7.2. Determination of Decision Makers, Alternatives and Criterion

Facility location selection is a very first and important decision step among the investment decisions this is not only because it has a certain impact on fixed costs of establishment but also its effect on the future variable costs. Many different criteria such as transportation sources, proximity to market, proximity to raw material, labor costs, energy/water requirements, costs of land and etc., have to be considered during the process of facility location selection. 5 different criterions have been selected for this study.

In this study, first of all a committee of four decision makers (D1, $D_2$, $D_3$, $D_4$) are selected. Objective is defined as finding optimal location for plastic factory among four alternatives which are (A1, $A_2$, $A_3$, $A_4$). Evaluation criteria (C1, C2, C3, C4, C5) have also been determined as can be shown explicitly in figure 7.1, in the below hierarchical structure of the problem.

✓ **Transportation($C_1$)**

Transportation is a significant criteria to consider as it has a certain impact on costs and therefore on facility location selection decisions. With the logic of JIT, in the future the aim is to deliver materials to concerned factories as much frequent as possible. Therefore how close the selected location is and how good transportation sources of selected location are have a certain impact on costs and efficiency of production system. It is significant to provide that the new established factory has to be located close to the facility of other six factories in order to assure the easiness of transport conditions.

✓ **Proximity to Raw Materials ($C_2$)**

Transportation costs of raw material supply to the factory also consist of a great portion among the expenditure item. New plastic factory will serve to 6 factories as much as its total capacity, it can be estimated how frequent raw materials will be transported to factory. Therefore, selected alternatives have to be analyzed with respect to the sources of raw materials and the existence of potential suppliers.

✓ **Energy and Water Sources ($C_3$)**

It is a certain fact that the facility requirement for energy and water will affect the costs in a large portion. Therefore it is important to establish related factory in a location that the energy and water sources are cheaper comparing to other alternatives.

✓ **Labor Force ($C_4$)**

It is easy to observe that plastic injection production requires not only experienced and qualified blue collar but also white collar employees. It has to be analyzed in details if the labor force is both quantitatively and qualitatively adequate. Selected location should also provide necessary conditions that employees and their families can live during their carrier.

✓ **Costs of Land (C5)**

The first and the most important cost item at the beginning of the establishment process is the investment on the land. Selected location also should not be a constriction for further expanding strategies of the factory.

Potential facility location alternatives are defined as Tekirdağ (A1), Hadımköy(A2), Gebze (A3) and Yalova (A4). These alternatives are especially selected depending on the proximity to location of the facility that it is going to serve and closeness to related industries depending on the meeting qualified labor force requirement.

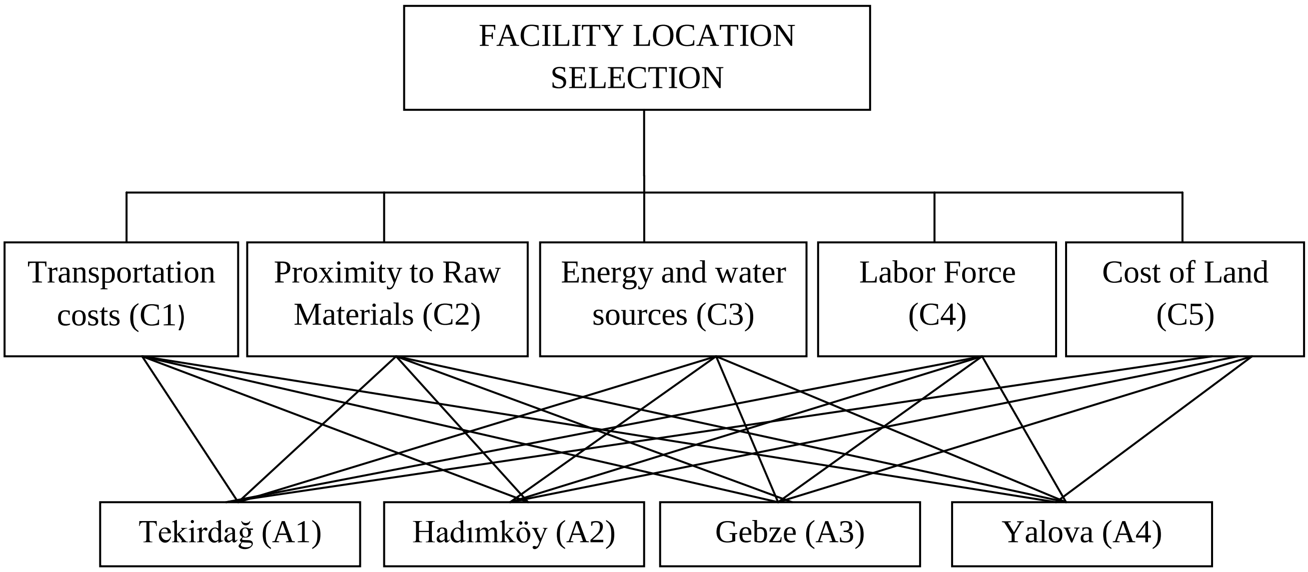


**Figure 7.1**: Hierarchical structure of facility location selection methodology

### 7.3. Application of Fuzzy TOPSIS Methodology

The aim of this section is to select most suitable location among alternatives by applying fuzzy TOPSIS. How the decision-makers, location alternatives and criterions are selected was shown in previous sections. In this section, first of all alternatives are evaluated by decision makers through the use of linguistic variables and afterwards evaluations are converted to triangular fuzzy numbers. Then necessary calculations are conducted to estimate closeness coefficients as explained in above sections and later these coefficients are ordered beginning from the largest to smallest for the purpose of attaining a priority order among the alternatives. At last, alternative in the first rank was selected by decision makers.

#### 7.3.1. Evaluation of Criterions and Alternatives by Decision-Makers

As previously explained, importance weights of decision criteria have to be evaluated and converted in to triangular fuzzy numbers by using table 4.1 in which linguistic variables and their equivalents as triangular fuzzy numbers from lowest (VL) to highest (VH) were demonstrated. Moreover in table 4.2, linguistic variables and their equivalents as triangular fuzzy numbers to evaluate alternatives with respect to selected decision criteria were also defined beginning from very poor (VP) to very good (VG).

First of all 4 decision-makers which are working as engineers in the facility as previously explained in section 7.1 started the process by evaluating importance weight of each criterion with the help of linguistic variables in table 4.1. Below table of 7.1 represents the results of how decision-makers evaluate each decision criteria by linguistic variables.

**Table 7.1:** Importance weights of evaluation criteria with respect to decision makers

| CRITERIA | DECISION-MAKERS | | | |
|---|---|---|---|---|
| | D1 | D2 | D3 | D4 |
| C1 | H | VH | H | VH |
| C2 | VH | H | VH | H |
| C3 | MH | H | M | MH |
| C4 | VH | MH | H | VH |
| C5 | MH | H | MH | H |

Importance weight of each criteria are evaluated by decision-makers as linguistic variables and have to be converted to triangular fuzzy numbers in order to be used in further steps of the proposed methodology. Linguistic variables are replaced by their equivalent triangular fuzzy numbers by using table 4.1. For instance under the assumption that one of the decision-makers evaluates one of the criteria as high, then the membership function of this evaluation for the importance weight of criteria is (0.7, 0.8, 0.9) as given in the related table of 4.2. and by this way it becomes possible to transform linguistic variables in to triangular fuzzy numbers. In the following table of 7.2, evaluation results of decision-makers are converted and expressed as triangular fuzzy numbers.

**Table 7.2:** Expression of evaluation results as triangular fuzzy numbers

| CRITERIA | DECISION-MAKERS | | | |
|---|---|---|---|---|
| | **D1** | **D2** | **D3** | **D4** |
| C1 | (0.7, 0.8, 0.9) | (0.8, 1, 1) | (0.7, 0.8, 0.9) | (0.8, 1, 1) |
| C2 | (0.8, 1, 1) | (0.7, 0.8, 0.9) | (0.8, 1, 1) | (0.7, 0.8, 0.9) |
| C3 | (0.5, 0.65, 0.8) | (0.7, 0.8, 0.9) | (0.4, 0.5, 0.6) | (0.5, 0.65, 0.8) |
| C4 | (0.7, 0.8, 0.9) | (0.5, 0.65, 0.8) | (0.7, 0.8, 0.9) | (0.8, 1, 1) |
| C5 | (0.5, 0.65, 0.8) | (0.7, 0.8, 0.9) | (0.5, 0.65, 0.8) | (0.7, 0.8, 0.9) |

In the next step of the algorithm decision-makers evaluate each location alternative by using the linguistic variables shown in table 4.2. In the below table 7.3, there exists evaluation results of alternatives by using linguistic variables with respect to each criteria and in the second below table of 7.4, related results are converted to fuzzy triangular numbers.

**Table 7.3:** Evaluation results of four alternatives by decision-makers with respect to selected criterions

| **CRITERIA** | **ALTERNATIVES** | **DECISION-MAKERS** | | | |
|---|---|---|---|---|---|
| | | D1 | D2 | D3 | D4 |
| C1 | A1 | VG | VG | VG | VG |
| | A2 | G | VG | G | G |
| | A3 | MG | G | G | MG |
| | A4 | G | MG | MG | G |
| C2 | A1 | VG | G | VG | VG |
| | A2 | VG | VG | G | VG |
| | A3 | F | MG | F | MG |
| | A4 | MG | F | MG | F |
| C3 | A1 | VG | VG | G | VG |
| | A2 | G | G | VG | G |
| | A3 | G | MG | MG | G |
| | A4 | MG | G | MG | F |
| C4 | A1 | VG | G | VG | VG |
| | A2 | VG | G | G | G |
| | A3 | MG | G | F | G |
| | A4 | F | MG | G | F |
| C5 | A1 | F | MG | MP | F |
| | A2 | MG | F | P | MG |
| | A3 | VG | G | MG | VG |
| | A4 | MG | F | G | G |

**Table 7.4:** Evaluation results of 4 alternatives by 4 decision-makers under the selected criteria as expressed by triangular fuzzy numbers.

| CRITERIA | ALTERNATIVES | DECISION-MAKERS | | | |
|---|---|---|---|---|---|
| | | D1 | D2 | D3 | D4 |
| C1 | A1 | (8, 10, 10) | (8, 10, 10) | (8, 10, 10) | (8, 10, 10) |
| | A2 | (7, 8, 9) | (8, 10, 10) | (7, 8, 9) | (7, 8, 9) |
| | A3 | (5, 6.5, 8) | (7, 8, 9) | (7, 8, 9) | (5, 6.5, 8) |
| | A4 | (7, 8, 9) | (5, 6.5, 8) | (5, 6.5, 8) | (7, 8, 9) |
| C2 | A1 | (8, 10, 10) | (7, 8, 9) | (8, 10, 10) | (8, 10, 10) |
| | A2 | (8, 10, 10) | (8, 10, 10) | (7, 8, 9) | (8, 10, 10) |
| | A3 | (4, 5, 6) | (5, 6.5, 8) | (4, 5, 6) | (5, 6.5, 8) |
| | A4 | (5, 6.5, 8) | (4, 5, 6) | (5, 6.5, 8) | (4, 5, 6) |
| C3 | A1 | (8, 10, 10) | (8, 10, 10) | (8, 10, 10) | (8, 10, 10) |
| | A2 | (7, 8, 9) | (7, 8, 9) | (8, 10, 10) | (7, 8, 9) |
| | A3 | (7, 8, 9) | (5, 6.5, 8) | (5, 6.5, 8) | (7, 8, 9) |
| | A4 | (5, 6.5, 8) | (7, 8, 9) | (5, 6.5, 8) | (4, 5, 6) |
| C4 | A1 | (8, 10, 10) | (7, 8, 9) | (8, 10, 10) | (8, 10, 10) |
| | A2 | (8, 10, 10) | (7, 8, 9) | (7, 8, 9) | (7, 8, 9) |
| | A3 | (5, 6.5, 8) | (7, 8, 9) | (4, 5, 6) | (7, 8, 9) |
| | A4 | (4, 5, 6) | (5, 6.5, 8) | (7, 8, 9) | (4, 5, 6) |
| C5 | A1 | (4, 5, 6) | (5, 6.5, 8) | (2, 3.5, 5) | (4, 5, 6) |
| | A2 | (5, 6.5, 8) | (4, 5, 6) | (1, 2, 3) | (5, 6.5, 8) |
| | A3 | (8, 10, 10) | (7, 8, 9) | (5, 6.5, 8) | (8, 10, 10) |
| | A4 | (5, 6.5, 8) | (4, 5, 6) | (7, 8, 9) | (7, 8, 9) |

### 7.3.2. Structuring Fuzzy Decision Matrix and Normalized fuzzy decision matrix

Fuzzy decision matrix is constructed by making use of the evaluation results of alternatives with respect to decision criteria. Related formulas to calculate the values of fuzzy decision matrix and aggregated fuzzy weights ($\hat{W}_{ij}$) of each criterion are represented with the equations of 4.1, 4.2, and 4.3. As further explained after constructing the fuzzy decision matrix, it has to be normalized. With the objective of generating normalized fuzzy decision matrix, linear scale transformation will be applied instead of applying complex normalization formula of traditional TOPSIS.

**Table 7.5:** Fuzzy Decision Matrix and fuzzy weights of four alternatives

| | **A1** | **A2** | **A3** | **A4** | **Weight** |
|---|---|---|---|---|---|
| **C1** | (8, 10, 10) | (7, 8.5, 10) | (5, 7.2, 9) | (5, 7.3, 9) | (0.7, 0.9, 1) |
| **C2** | (7, 9.5, 10) | (7, 9.5, 10) | (4, 5.8, 8) | (4, 5.8, 8) | (0.7, 0.9, 1) |
| **C3** | (8,10,10) | (7, 8.5, 10) | (5, 6.7, 9) | (5, 6.5, 9) | (0.4, 0.65, 0.9) |
| **C4** | (7, 9.5, 10) | (7, 8.5, 10) | (4, 6.8, 9) | (4, 6.1, 9) | (0.5, 0.82, 1) |
| **C5** | (2, 5,8) | (1, 5, 8) | (5, 8.62, 10) | (4, 6.8, 9) | (0.5, 0.73, 0.9) |

**Table 7.6:** Normalized fuzzy decision matrix

| | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|
| **C1** | (0.8, 1, 1) | (0.7, 0.85, 1) | (0.5, 0.72, 0.9) | (0.5, 0.73, 0.9) |
| **C2** | (0.7, 0.95, 1) | (0.7, 0.95, 1) | (0.4, 0.58, 0.8) | (0.4, 0.58, 0.8) |
| **C3** | (0.8, 1, 1) | (0.7, 0.85, 1) | (0.5, 0.67, 0.9) | (0.5, 0.65, 0.9) |
| **C4** | (0.7, 0.95, 1) | (0.7, 0.85, 1) | (0.4, 0.68, 0.9) | (0.4, 0.61, 0.9) |
| **C5** | (0.2, 0.5, 0.8) | (0.1, 0.5, 0.8) | (0.5, 0.86, 1) | (0.4, 0.68, 0.9) |

The next step of the algorithm is to calculate weighted normalized fuzzy matrix by multiplying the importance weights of evaluation criteria and the values in the normalized fuzzy decision matrix. In order to compute weighted normalized decision matrix which can be seen in below table 7.7, equation 4.8 has to be applied.

**Table 7.7:** Weighted Normalized fuzzy decision matrix

| | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|
| **C1** | (0.56, 0.9, 1) | (0.49, 0.76, 1) | (0.35, 0.64, 0.9) | (0.35, 0.66, 0.9) |
| **C2** | (0.49, 0.85, 1) | (0.49, 0.85, 1) | (0.28, 0.45, 0.8) | (0.28, 0.52, 0.8) |
| **C3** | (0.32, 0.65, 0.9) | (0.28, 0.55, 0.9) | (0.20, 0.43, 0.81) | (0.20, 0.42, 0.81) |
| **C4** | (0.35, 0.78, 1) | (0.35, 0.41, 1) | (0.20, 0.56, 0.9) | (0.20, 0.50, 0.9) |
| **C5** | (0.05, 0.26, 0.64) | (0.05, 0.36, 0.72) | (0.25, 0.63, 0.9) | (0.20, 0.50, 0.81) |

Fuzzy positive ideal (FPIS, $A^*$) and fuzzy negative ideal (FNIS, $A^-$) solutions are determined after a weighted normalized fuzzy decision matrix is generated as explained by Chen et al., (2006). Equation 4.10a and 4.10b are applied to compute related elements.

$$A^{*} = [(1, 1, 1), (1, 1, 1), (0.90, 0.90, 0.90), (1, 1, 1), (0.90, 0.90, 0.90)] \quad (7.1a)$$

$$A^{-} = [(0.35, 0.35, 0.35), (0.28, 0.28, 0.28), (0.20, 0.20, 0.20), (0.20, 0.20, 0.20), (0.05, 0.05, 0.05)] \quad (7.1b)$$

After $A^{*}$ and $A^{-}$ are determined respectively, the distance of each alternative from FPIS and FNIS with respect to each criterion are calculated by using vertex method as following:

$$d(A_1, A^{*}) = \sqrt{\frac{1}{3}(1-056)^2 + (1-0.9)^2 + (1-1)^2} = 0.26 \quad (7.2a)$$

$$d(A_1, A^{-}) = \sqrt{\frac{1}{3}(0.35-056)^2 + (0.35-0{,}9)^2 + (0.35-1)^2} = 0{,}5 \quad (7.2b)$$

In this paper, only the calculations of the distance of the first alternative to FPIS $d(A_1, A^{*})$ and FNIS $d(A_1, A^{-})$ will be demonstrated explicitly. The same calculations were conducted for all alternatives for each and every criterion. Related results can be shown in table 7.8 and 7.9 as follows:

**Table 7.8:** Distance of each alternative [$A_i$ = (i = 1, 2, 3, 4)] from FPIS with respect to each criterion

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| **$d(A_1, A^*)$** | 0.26 | 0.306 | 0.392 | 0.396 | 0.632 |
| **$d(A_2, A^*)$** | 0.325 | 0.306 | 0.411 | 0.5 | 0.59 |
| **$d(A_3, A^*)$** | 0.432 | 0.535 | 0.489 | 0.53 | 0.495 |
| **$d(A_4, A^*)$** | 0.427 | 0.512 | 0.492 | 0.547 | 0.468 |

**Table 7.9:** Distance of each alternative [$A_i$ = ( i = 1, 2, 3, 4)] from FPIS with respect to each criterion

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| **d ($A_1$, $A^-$)** | 0.5 | 0.543 | 0.485 | 0.6 | 0.36 |
| **d ($A_2$, $A^-$)** | 0.45 | 0.543 | 0.454 | 0.485 | 0.426 |
| **d ($A_3$, $A^-$)** | 0.358 | 0.315 | 0.376 | 0.454 | 0.605 |
| **d ($A_4$, $A^-$)** | 0.364 | 0.330 | 0.374 | 0.439 | 0.517 |

After making necessary calculations to estimate the distance of each alternative from FPIS and FNIS with respect to each criterion the results are summarized in table 7.8 and 7.9. To attain these values of $d_i^*$ and $d_i^-$ of four alternatives will be calculated by using equation 4.12a – 4.12b whereas closeness coefficient ($CC_i$ ) will be computed by equation 4.13. $d_v$ (.,.) represents the distance measurement between two fuzzy numbers whereas a closeness coefficient ($CC_i$) is necessary to rank all possible alternatives. As stated by Eruğrul & Karakaşoğlu correspondence values of closeness coefficient ($CC_i$) are the distances to the fuzzy positive ideal solution and fuzzy negative ideal solution ($A^-$). Below table 7.10 demonstrates computation results of $d_i^*$, $d_i^-$ and $CC_i$.

According to this step of the algorithm, closeness coefficients are calculated by below equation of 25 as further explained and taken by Chen (2000).

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad i = 1, 2, \dots m \tag{7.3}$$

Closeness coefficient calculations of 4 alternatives are as follows:

$$CC_1 = \frac{2.488}{2.488 + 1.986} = 0.556 \tag{7.4a}$$

$$CC_2 = \frac{2.358}{2.358 + 2.132} = 0.525 \tag{7.4b}$$

$$CC_3 = \frac{2.108}{2.108 + 2.481} = 0.459 \tag{7.4c}$$

$$CC_4 = \frac{2.024}{2.024 + 2.446} = 0.452 \qquad (7.4d)$$

**Table 7.10:** Result of Fuzzy TOPSIS Methodology

| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | Ranking order |
|---|---|---|---|---|---|
| $d_i^*$ | 1.986 | 2.132 | 2.481 | 2.446 | $A_1>A_2>A_3>A_4$ |
| $d_i^-$ | 2.488 | 2.358 | 2.108 | 2.024 | |
| $CC_i$ | 0.556 | 0.525 | 0.459 | 0.452 | |

### 7.4. Fuzzy AHP Methodology

In this study, as it can be seen in the application of Fuzzy TOPSIS method, a committee of four decision-makers is available to define the ranking of determined alternatives through the selected methods of fuzzy AHP. As the evaluations of decision-makers include subjective opinions and cannot be represented by quantitative data, fuzzy adapted multi-criteria decision making methods are selected on purpose. In this study, opinions of the decision-makers are converted to fuzzy triangular numbers as they can be used in related methodologies. Objective of this part of the thesis is to select optimal location for the new-established factory through fuzzy AHP approach and able to make a comparison between the results attained already by fuzzy TOPSIS.

#### 7.4.1. Application of Fuzzy AHP Methodology

In this section of the thesis, Fuzzy AHP method will be applied to the same problem of location selection as it was solved by fuzzy TOPSIS in previous section. Proposed methodology to solve this problem was firstly introduced by Chang (1996). In order to make proper comparisons with the results, four decision-makers and criteria will stay the same. As the first step of the AHP approach, decision-makers will conduct pair-wise comparisons individually according to the Saaty's scale for pair-wise comparison and results will be expressed in matrixes such as below matrix.

$$D_p = \begin{bmatrix} b_{11p} & b_{12p} & \dots & b_{1mp} \\ b_{21p} & b_{22p} & \dots & b_{2mp} \\ \vdots & \vdots & \dots & \vdots \\ b_{m1p} & b_{m2p} & \dots & b_{mmp} \end{bmatrix} \quad p = 1, 2, \dots t \qquad (7.5)$$

In order to generate pair-wise comparison matrixes of five different criteria, decision-makers are questioned in such a manner to ensure that they can determine importance weights of selected criteria. It was aimed that experts conduct pair-wise comparisons on the scale of equal importance, somewhat more important, much more important, very much more important, and absolutely more important as defined by Saaty's Scale which was addresses in table 7.11. In traditional AHP, Saaty's scale is adequate to define importance weights of criterion. However; in fuzzy environment after comparing selected criteria pair-wisely related values of linguistic variables have to be transformed in to fuzzy numbers by using formulas in equation 4.24a, 4.24b and 4.24c or by using another converting table like the one that Alkan & Akman applied in their study for performance evaluation of suppliers through the method of fuzzy AHP.

**Table 7.11:** The Saaty Rating Scale
***http://www.booksites.net/download/coyle/student_files/AHP_Technique.pdf***

| Intensity of Importance | Definition | Explanation |
|---|---|---|
| 1 | Equal Importance | Two factors contribute equally to the objective |
| 3 | Somewhat more important | Experience and judgment slightly favor one over the other |
| 5 | Much more important | Experience and judgment strongly favor one over the other |
| 7 | Very much more important | Experience and judgment strongly favor one over the other. Its importance is demonstrated in practice. |
| 9 | Absolutely more important | The evidence favoring one over the other is of the highest possible validity. |
| 2, 4, 6, 8 | Intermediate values | When compromise is needed. |

In the following section pair-wise comparison of five criterions with respect to each decision-maker {D1, $D_2$, $D_3$, $D_4$} will be presented in below tables 7.12, 7.13, 7.14, 7.15 and 7.16:

**Table 7.12:** Pair-wise comparison of 5 criterions with respect to $D_1$

| $D_1$ | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| **C1** | 1 | 3 | 5 | 3 | 7 |
| **C2** | 1/3 | 1 | 5 | 5 | 7 |
| **C3** | 1/5 | 1/5 | 1 | 3 | 3 |
| **C4** | 1/3 | 1/5 | 1/3 | 1 | 5 |
| **C5** | 1/7 | 1/7 | 1/3 | 1/5 | 1 |

**Table 7.13:** Pair-wise comparison of 5 criterions with respect to $D_2$

| D2 | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| **C1** | 1 | 3 | 5 | 3 | 7 |
| **C2** | 1/3 | 1 | 5 | 3 | 5 |
| **C3** | 1/5 | 1/5 | 1 | 3 | 3 |
| **C4** | 1/3 | 1/3 | 1/3 | 1 | 5 |
| **C5** | 1/7 | 1/5 | 1/3 | 1/5 | 1 |

**Table 7.14:** Pair-wise comparison of 5 criterions with respect to $D_3$

| $D_3$ | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| **C1** | 1 | 1 | 5 | 3 | 5 |
| **C2** | 1 | 1 | 3 | 3 | 5 |
| **C3** | 1/5 | 1/3 | 1 | 1/3 | 3 |
| **C4** | 1/3 | 1/3 | 3 | 1 | 5 |
| **C5** | 1/5 | 1/5 | 1/5 | 1/5 | 1 |

**Table 7.15:** Pair-wise comparison of 5 criterions with respect to $D_4$

| $D_4$ | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| **C1** | 1 | 3 | 5 | 3 | 5 |
| **C2** | 1/3 | 1 | 3 | 1 | 3 |
| **C3** | 1/5 | 1/3 | 1 | 1/5 | 1 |
| **C4** | 1/3 | 1 | 5 | 1 | 3 |
| **C5** | 1/5 | 1/3 | 1 | 1/3 | 1 |

The next step of the methodology is to construct a comprehensive pair-wise matrix by using the formulas in equation 4.24a, 4.24b and 4.24c, in order to integrate decision of four decision-makers.

**Table 7.16:** Fuzzy Evaluation Matrix with respect to goal

| $D_4$ | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| **C1** | (1, 1, 1) | (1, 2.5, 3) | (5, 5, 5 ) | (3, 3, 3) | (5, 6, 7) |
| **C2** | (0.33, 0.5,1) | (1, 1, 1) | (3, 4, 5) | ( 1, 3, 5) | ( 3, 4, 7) |
| **C3** | (0.2, 0.2, 0.2) | (0.2, 0.26, 0.33) | (1, 1, 1) | (0.2, 1.63, 3) | (1, 2.5, 3) |
| **C4** | (0.33, 0.33, 0.33) | (0.2, 0.46, 1) | (0.33, 2.16,5) | (1, 1, 1) | (3, 4.5, 5) |
| **C5** | (0.14 , 0.17, 0.2) | (0.14, 0.22, 0.33) | (0.2, 0.46, 1) | (0.2, 0.23,0.33) | (1, 1, 1) |

From the table 7.16 according to extent analysis synthesis values with respect to main goals are calculated by using equation 4.14 as follows:

$$S_{c1}= (15, 17.5, 19) \text{ x } (1/ 60.72, 1/ 46.12, 1/32.47) = (0.247, 0.379, 0.585) \quad (7.6a)$$

$$S_{c2}= (8.33, 12.5, 19) \text{ x } (1/ 60.72, 1/ 46.12, 1/32.47) = (0.137, 0.271, 0.585) \quad (7.6b)$$

$$S_{c3}= (2.6, 5.59, 7.53) \text{ x } (1/ 60.72, 1/ 46.12, 1/32.47) = (0.043, 0.121, 0.232) \quad (7.6c)$$

$S_{c4}$= (4.86, 8.45, 12.33) x (1/ 60.72, 1/ 46.12, 1/32.47) = (0.08, 0.183, 0.38) (7.6d)

$S_{c5}$= (1.68, 2.08, 2.86) x (1/ 60.72, 1/ 46.12, 1/32.47) = (0.028, 0.045, 0.088) (7.6e)

By using equation 4.20, fuzzy values are compared to each other and following results in table 7.17 is attained.

**Table 7.17:** Comparison of Fuzzy Values

| | | | | |
|---|---|---|---|---|
| V ($S_{c1} \geq S_{c2}$) = 1 | V ($S_{c2} \geq S_{c1}$) = 0.758 | V ($S_{c3} \geq S_{c1}$) = 0 | V ($S_{c4} \geq S_{c1}$) = 0.404 | V ($S_{c5} \geq S_{c1}$) = 0 |
| V ($S_{c1} \geq S_{c3}$) = 1 | V ($S_{c2} \geq S_{c3}$) = 1 | V ($S_{c3} \geq S_{c2}$) = 0.388 | V ($S_{c4} \geq S_{c2}$) = 0,734 | V ($S_{c5} \geq S_{c2}$) = 0 |
| V ($S_{c1} \geq S_{c4}$) = 1 | V ($S_{c2} \geq S_{c4}$) = 1 | V ($S_{c3} \geq S_{c4}$) = 0.71 | V ($S_{c4} \geq S_{c3}$) = 1 | V ($S_{c5} \geq S_{c3}$) = 0,238 |
| V ($S_{c1} \geq S_{c5}$) = 1 | V ($S_{c2} \geq S_{c5}$) = 1 | V ($S_{c3} \geq S_{c5}$) = 1 | V ($S_{c4} \geq S_{c5}$) = 1 | V ($S_{c5} \geq S_{c4}$) = 0,055 |

The next step in the algorithm is to compute the priority weights by using equation 4.21a, 4.21b and 4.21c. Results can be found below with equations 7.7.

d' ($C_1$) = min (1, 1, 1, 1) = 1 (7.7a)

d' ($C_2$) = min (0.758, 1, 1, 1 ) = 0.758 (7.7b)

d' ($C_3$) = min (0, 0.388, 0,71, 1) = 0 (7.7c)

d' ($C_4$) = min (0.404, 0.734, 1, 1) = 0.404 (7.7d)

d' ($C_5$) = min (0, 0, 0.238, 0.055) = 0 (7.7e)

Priority Weights from W'= [1, 0.758, 0, 0.404, 0] vector. These values have to be normalized in order to obtain priority weight respect to main goal. After the normalization priority weights with respect to main goal is calculated as:

W'= [0.463, 0.351, 0, 0.187, 0] (7.8)

After the priority weights of the criteria are determined, priority of alternatives has to be determined with respect to each criterion. Depending on pair-wise comparisons of decision-makers for alternatives, evaluation matrixes are generated as in the below tables of 7.18, 7.19, 7.20, 7.21 and 7.22.

**Table 7.18:** Fuzzy Evaluation Matrix with respect to $C_1$

| C1 | A1 | A2 | A3 | A4 |
|---|---|---|---|---|
| **A1** | (1, 1, 1) | (1, 3, 5) | (3, 4.5 , 5) | (3, 4.5 , 5) |
| **A2** | (0.33, 0.46, 1) | (1, 1, 1) | (3, 3, 3) | (3, 4.5 , 5) |
| **A3** | (0.2, 0.23, 0.33) | (0.33, 0.33, 0.33) | (1, 1, 1) | (1, 2, 3) |
| **A4** | (0.2, 0.23, 0.33) | (0.2, 0.23, 0.33) | (0.33, 0.66, 1) | (1, 1, 1) |

**Table 7.19:** Fuzzy Evaluation Matrix with respect to $C_2$

| C2 | A1 | A2 | A3 | A4 |
|---|---|---|---|---|
| **A1** | (1, 1, 1) | (1, 3, 5) | (3, 4.5, 5) | (3, 5, 7) |
| **A2** | (0.2 , 0.46, 1) | (1, 1, 1) | (3, 3, 3) | (1, 4, 5) |
| **A3** | (0.2, 0.23, 0.33) | (0.33, 0.33, 0.33) | (1, 1, 1) | (3, 3, 3) |
| **A4** | (0.14, 0.22, 0.33) | (0.2, 0.4, 1) | (0.33, 0.33, 0.33) | (1, 1, 1) |

**Table 7.20:** Fuzzy Evaluation Matrix with respect to $C_3$

| C3 | A1 | A2 | A3 | A4 |
|---|---|---|---|---|
| **A1** | (1, 1, 1) | (1, 3, 5) | (3, 3.5, 5) | (3, 4, 7) |
| **A2** | (0.2, 0.46, 1) | (1, 1, 1) | (3, 3.5, 5) | (3, 4, 5) |
| **A3** | (0.2,0.3, 0.33) | (0.2,0.3, 0.33) | (1, 1, 1) | (1, 2, 3) |
| **A4** | (0.14, 0.22, 0.33) | (0.2, 0.26, 0.33) | ( 0.33, 0.66, 1) | (1, 1, 1) |

**Table 7.21:** Fuzzy Evaluation Matrix with respect to $C_4$

| C4 | A1 | A2 | A3 | A4 |
|---|---|---|---|---|
| **A1** | (1, 1, 1) | (0.33, 0.83,1) | (0.14, 0.22, 0.33) | (0.2, 0.26, 0.33) |
| **A2** | (1, 2.5, 5) | (1, 1, 1) | (0.33, 0.33, 0.33) | (0.33, 0.66, 1) |
| **A3** | (3, 4, 7) | (3, 3,3 ) | (1, 1, 1) | (1, 1.5, 3) |
| **A4** | (3, 4, 5) | (1, 2, 3) | (0.33, 0.83, 1) | (1, 1, 1) |

**Table 7.22:** Fuzzy Evaluation Matrix with respect to $C_5$

| C5 | A1 | A2 | A3 | A4 |
|---|---|---|---|---|
| **A1** | (1, 1, 1) | (0.33, 1.17, 3) | (0.2, 0.29, 0.33) | (0,2 , 0.96, 3) |
| **A2** | (0.33, 1,33, 3) | (1, 1, 1) | (0.2, 0.29, 0.33) | (0.33, 0.83, 1) |
| **A3** | (3, 3.5, 5) | (3, 3.5, 5) | (1, 1, 1) | (1, 2, 3) |
| **A4** | (0.33, 2.83, 5) | (1, 2, 3) | (0.33, 0.66, 1) | (1, 1, 1) |

According to the algorithm, after computing the priority weights of each criterion was calculated priority weights of the alternatives with respect to each criterion also have to be calculated and summarized as in below table. The same calculations to calculate priority weights of criterion have been conducted to calculate priority weights of alternatives.

**Table 7.23:** Summary Table for priority weights of main attributes of the objective

| | C1 | C2 | C3 | C4 | C5 | Priority Weights |
|---|---|---|---|---|---|---|
| **Weight alternative** | 0,463 | 0,351 | 0 | 0,187 | 0 | |
| **$A_1$** | 0.577 | 0,603 | 0.0528 | 0.164 | 0.194 | 0,51 |
| **$A_2$** | 0.374 | 0,373 | 0.427 | 0.17 | 0.135 | 0,34 |
| **$A_3$** | 0.049 | 0,024 | 0.045 | 0.365 | 0.378 | 0,1 |
| **$A_4$** | 0 | 0 | 0 | 0.301 | 0.293 | 0,06 |

* The weight vector for first alternative from table 7.18 is calculated as (0.577, 0.603, 0.0528, 0.164, 0.194).

* The weight vector for second alternative from table 7.19 is calculated as (0.374, 0.373, 0.427, 0.17, 0.135, 0.34)

* The weight vector for third alternative from table 7.20 is calculated as (0.049 0.024, 0.045, 0.365, 0.378, 0.1)

* The weight vector for fourth alternative from table 7.21 is calculated as (0, 0, 0, 0. 301, 0.293)

On the next step in order to rank alternatives, priority weights of each alternative are calculated as follows:

$$A1 = 0,463*0,577 + \ldots\ldots\ldots \ldots 0*0,194 = 0.51 \tag{7.9a}$$

$$A2 = 0,463*0,374 + \ldots\ldots\ldots\ldots 0*0,135 = 0.34 \tag{7.9b}$$

$$A3 = 0,463*0,049 + \ldots\ldots\ldots\ldots 0*0,378 = 0.1 \tag{7.9c}$$

$$A4 = 0,463*0 + \ldots\ldots\ldots\ldots\ldots\ldots 0*0,293 = 0.06 \tag{7.9d}$$

First alternative has the highest priority among others and selected as the best facility location for plastic injection factory. The ranking order with fuzzy AHP is A1 > A2>A3>A4 which is also the same result that was attained by fuzzy TOPSIS. As transportation cost is defined as the most significant criterion, selecting first alternative which is closest to the company is a satisfactory result. After this step, the regional selection process has to be fulfilled and the same results can be repeated for specific locations within the selected region. Fuzzy AHP and TOPSIS methods can be applied not only for facility location but also for other kinds of multi-criteria decision making problems of a company. On the other hand it is really important to select the most proper methodology which depends on the problem type as both of related methodologies have some pros and cons. As taken from Ertuğrul and Karakaşoğlu (2007), a comparison of two methodologies is as follows:

* As it can be seen in the above application section; more complex computations are conducted to apply fuzzy AHP method comparing with fuzzy TOPSIS method.

* Fuzzy TOPSIS provides good results for one-tier decision tree whereas fuzzy AHP can be used for a wider spread of hierarchies in which less pair-wise comparisons are required for lower levels of the hierarchy (Bottani & Rizzi, 2006). On the other hand, for more complex structured problems, hierarchical fuzzy TOPSIS method was suggested by Kahraman et al., (2003)

* Different from fuzzy TOPSIS, fuzzy AHP requires pair-wise comparison (Kahraman et al., 2007).

* As can be seen according to above application of fuzzy TOPSIS, with the purpose of ranking alternatives, this method first calculates the relative distance of each alternative from negative and positive ideal solutions. On the other hand, in extent analysis of fuzzy AHP; decision makers conduct pair wise comparisons to define the priority weights of alternatives and criterions.

* In case a non-optimal alternative is presented and a change in ranking of the alternatives required, TOPSIS is declared as one of the best methods that can provide possible changes in the ranking of alternatives.

* To apply fuzzy AHP methodology, decision maker has to decide not only about its preference of one alternative on one criterion over another but also about the relative importance of one criterion against another which can be the most significant reason of

an increase in inconsistencies when the number of alternatives or criterions becomes larger causing a more difficult process of pair-wise comparison (Bottani&Rizzi, 2006).

* According to extent analysis of fuzzy AHP, introduced by Chang (1996); priority weights of alternatives or criterion can take the value of zero, meaning not to take the related criterion or alternative in to account which can be considered as a drawback of this method.

* Linguistic variables are in use both in fuzzy AHP and TOPSIS methodology.

* According to this study, same ranking orders are attained by applying fuzzy AHP and fuzzy TOPSIS methodologies which can be considered as a proof that same results can be taken from both of the methodologies providing that the decision maker is consistent while evaluating the necessary data.

Chang's Extent analysis method for fuzzy AHP was proposed. It has to be pointed out that in some cases it is not possible to calculate consistency when this method is used in this thesis. As a result of fuzzy AHP, total weighting vector of some criteria can be zero. While calculating the index of consistency, the first step is multiplying simplified pair wise comparison matrix with weighting vector. In the second step, the resulting matrix must be divided by each member of weighting factor one by one. When one of the members of weighting factor is zero, it is not possible to divide the related reel number by zero which is also indefinite in Mathematics ( Göksu & Güngör, 2008). Consistency analysis will not be applied with the concept of this study as weightings factors of some criteria is zero. Some other methodologies to make consistency analysis when related weighting factor is zero can be found in the literature.

# 8. CONCLUSION

Layout design problems consists of determining location parameters like placement of machines or departments. Layout design problem is strategically significant for any kind of organizations depending on the fact that layout design decisions affect system performance such as productivity, lead times; work in process and manufacturing transportation costs to a great extent. Additionally; with respect to its multi-objective nature and additional processes of data collecting, facility layout problem is one of the most challenging problems that many manufacturing companies confront with and has been widely studied in the literature.

The concept of facility location selection problem is basically identification of most suitable site for a firm to conduct its operations ensuring the objectives of cost minimization and maximization the use of resources. Location selection problems are strategically important since they are long-term, high-investment required and irreversible decisions. Additionally, location selection problems should be considered not only as a strategic level multi-criteria decision making problem but also a partly constructed process in supply chain management as the selection process can only be completed as a result of numerous logistical decisions. With respect to significance of the problem, many different approaches have been suggested to solve FLS problem. However, existing methodologies are not regarded as satisfactory depending on the ambiguity resulted from linguistic assessment. For the purpose of overcoming the vagueness inherent in facility location selection problems, fuzzy multi criteria decision making methods are proposed.

Depending on their strategic importance for any kind of organizations, this study is dedicated to solve these two problems. Basically, it can be summarized that the purpose of this study is to solve above mentioned facility layout design and facility location selection problem consecutively in a manufacturing company that locates in Tekirdağ region of Turkey. A detailed literature review which can be found in section 2 and section 3 was extremely beneficial two determine difficulties of problems, applied methodologies and their constraints. As a result, Excel add-in which proposes two different methodologies of optimal sequence and traditional CRAFT is selected for facility layout design whereas fuzzy TOPSIS and fuzzy AHP methodologies are suggested to solve location selection problem.

For layout design part; with the purpose of decreasing material handling costs, two different layout alternatives apart from initial layout were generated by a computer aided layout planning tool, namely CRAFT add-in. Related alternatives were generated by using different distance measures of Rectilinear and Euclidean. As a necessity to use CRAFT, current situation was analyzed, from-to and transport cost charts were then presented and best layout solution is aimed to be defined iteratively. According to data provided by CRAFT, new layouts were defined and re-drawn in a commercial CAD program. It has to be stated that, the final aim of applying this method was not only to minimize material handling costs but also to maximize the gain that can be attained from total departmental area and two of the aims are fulfilled in conclusion.

For layout selection section; two different fuzzy based methods, namely fuzzy AHP and TOPSIS are applied to prevent negativities that can be resulted from linguistic assessment. Two of the methods provided the same ranking. As transportation cost was evaluated as the most important criteria by decision-makers, the closest location was selected in the first rank. The results provided by each of the methods and the related methodologies were compared to each other at the end of this section. The results were found satisfactory by the management.

This research could be completed only after a long-term observation and data collection period which consisted of problem definition, literature research to find most suitable methodologies, data collection, analysis, solution and comparison of results. Necessary information were provided by ERP software which is currently used by the company, reports prepared by the related departments, and estimated figures of further years. On the other hand, people working in the managerial positions were selected as decision-makers to conduct facility location selection problem.

This study is unique since it was conducted in an existing company and with real data. On the other hand different from other research papers, it aimed to solve layout design and location selection problems of a company with the participation of engineers, operators and managers of related facility. As CRAFT presents a heuristic procedure and an idea for possible best layout design, the user of the program has always right to involve in the design process. The results were found suitable by directors since two different alternatives presented for layout design and two different methodologies were applied for location selection problem. More detailed evaluation of applied methodologies can be found at the end of related application sections.

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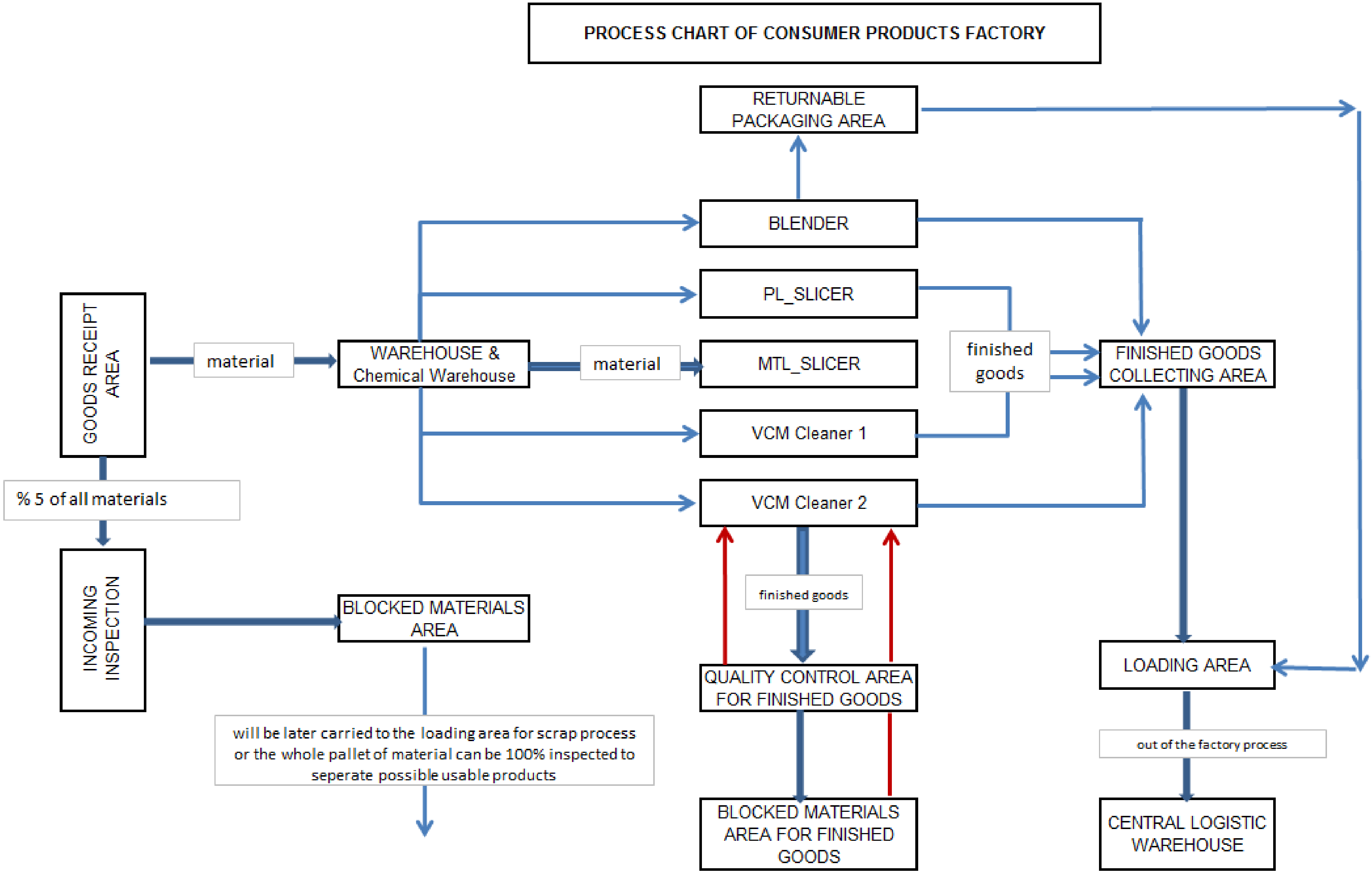
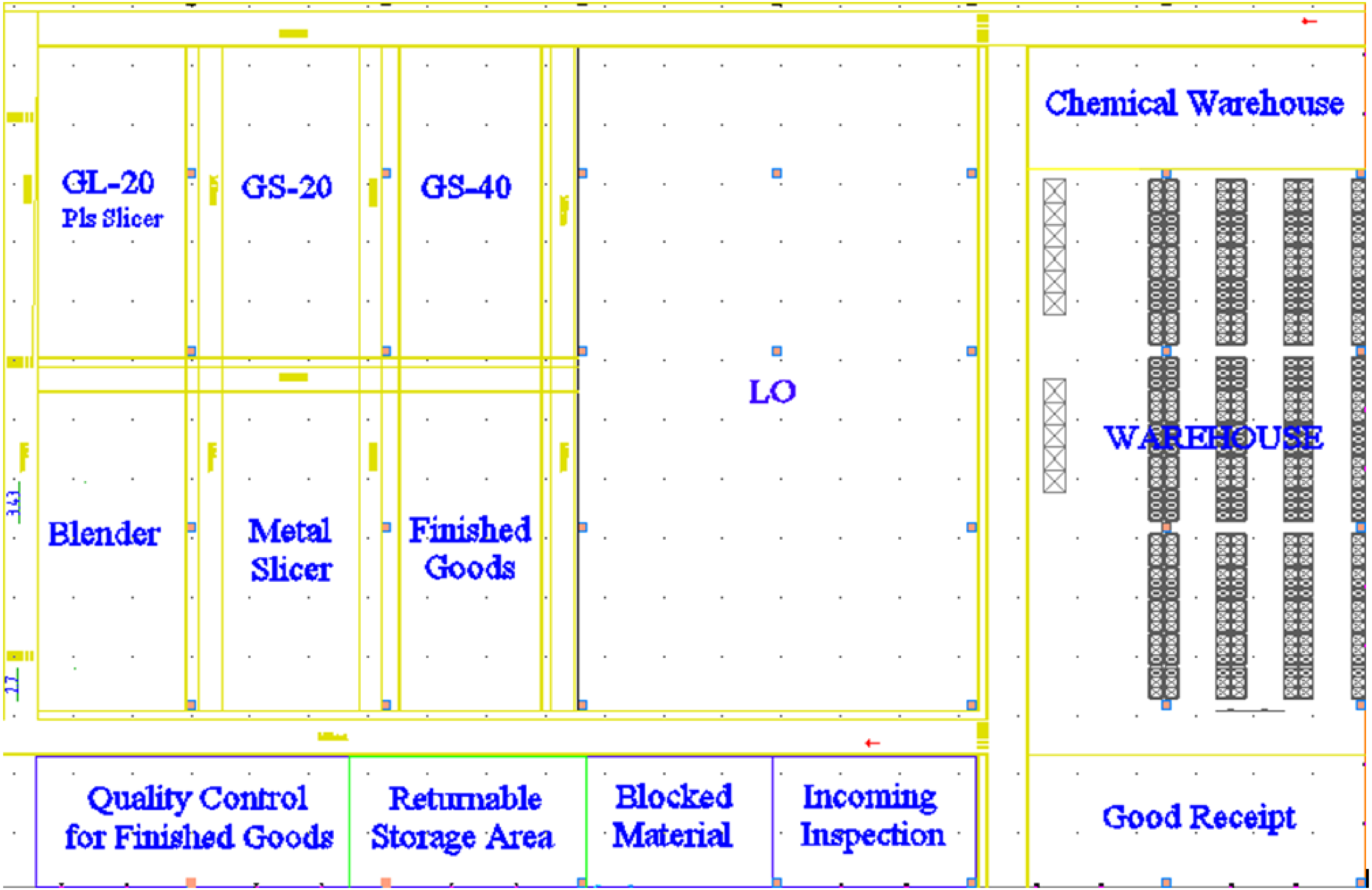
**Appendix A**




Goods Receipt Area is the same with loading area

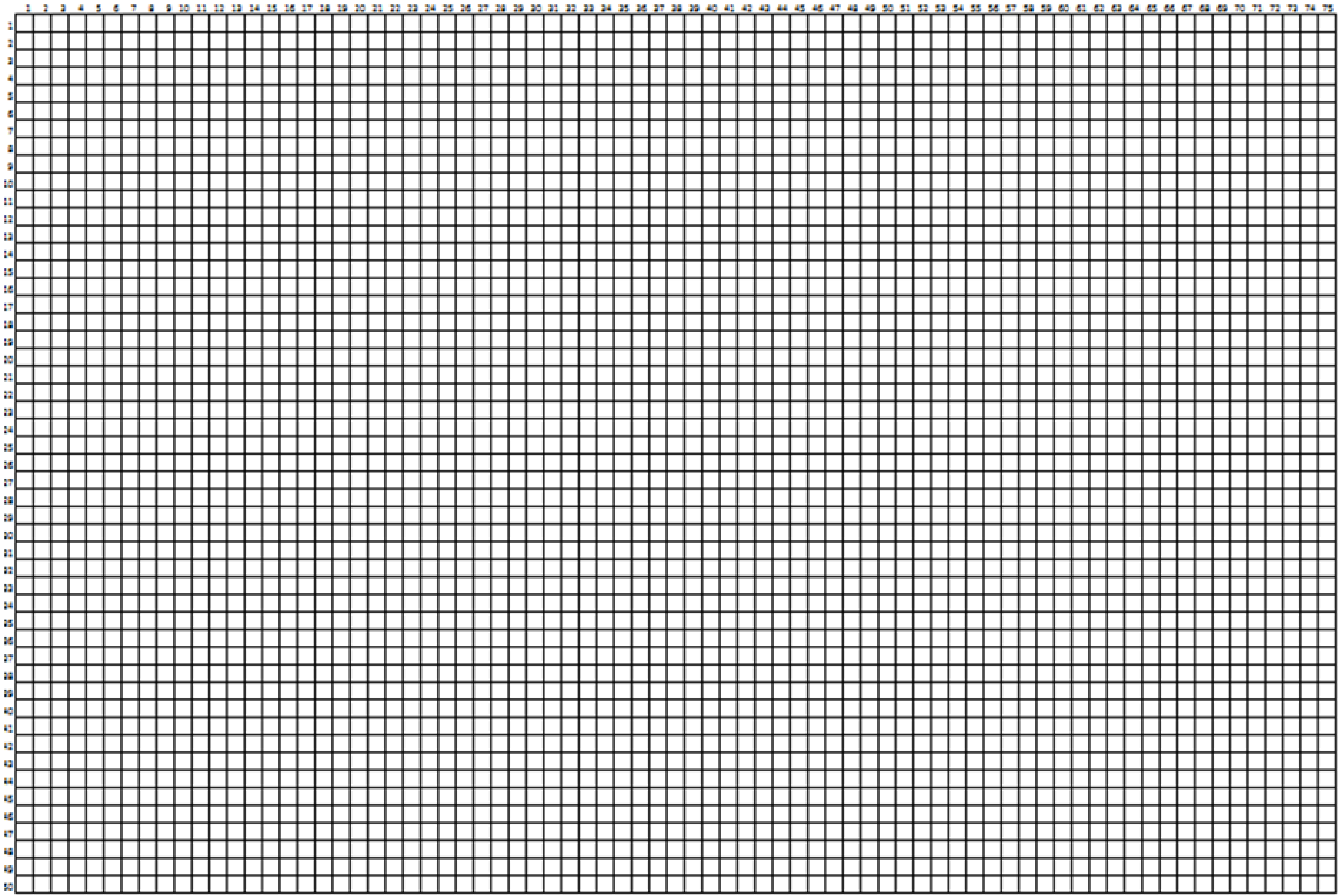
**Appendix B**

**Initial Layout**



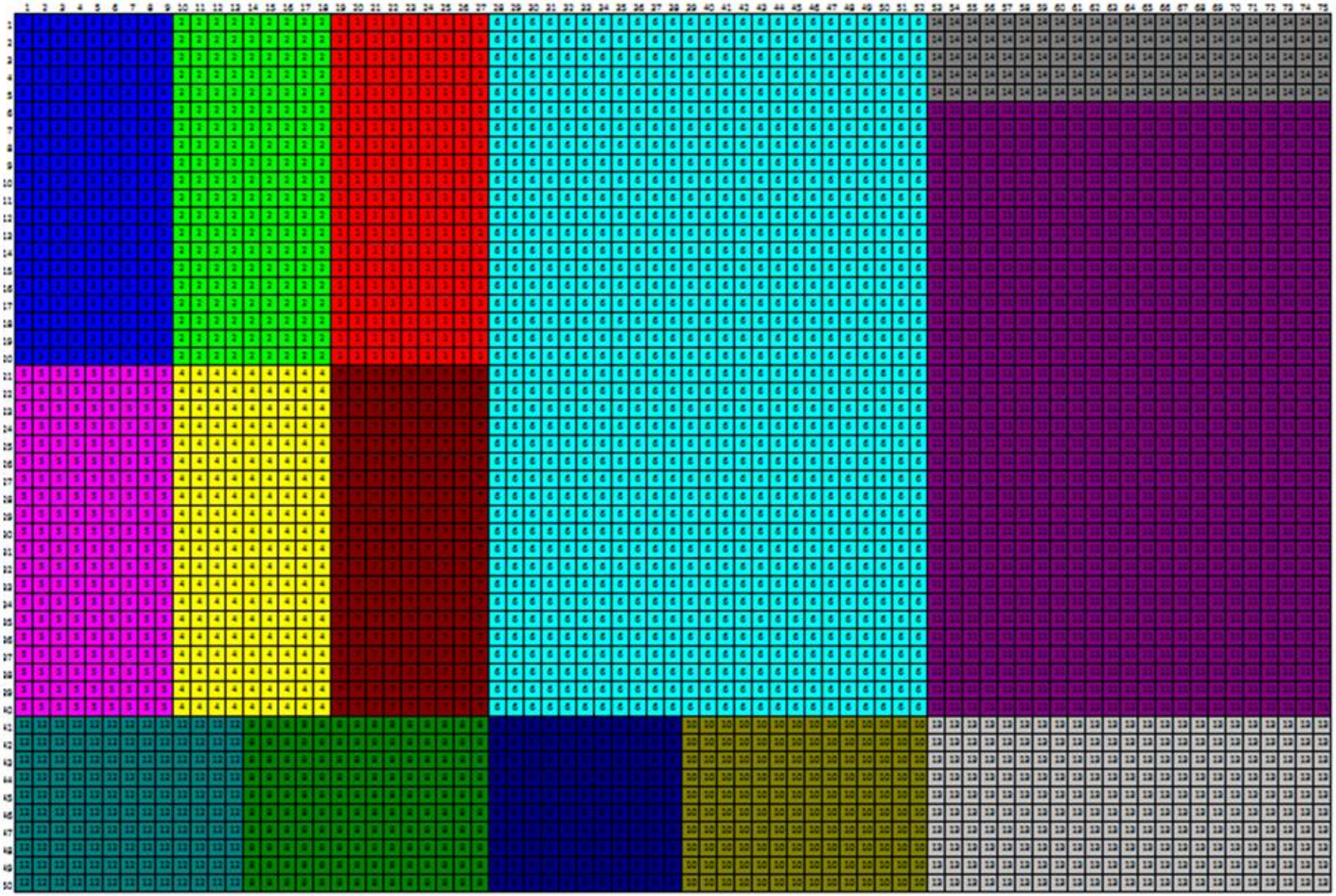
**Appendix C1**

**Blank Layout**



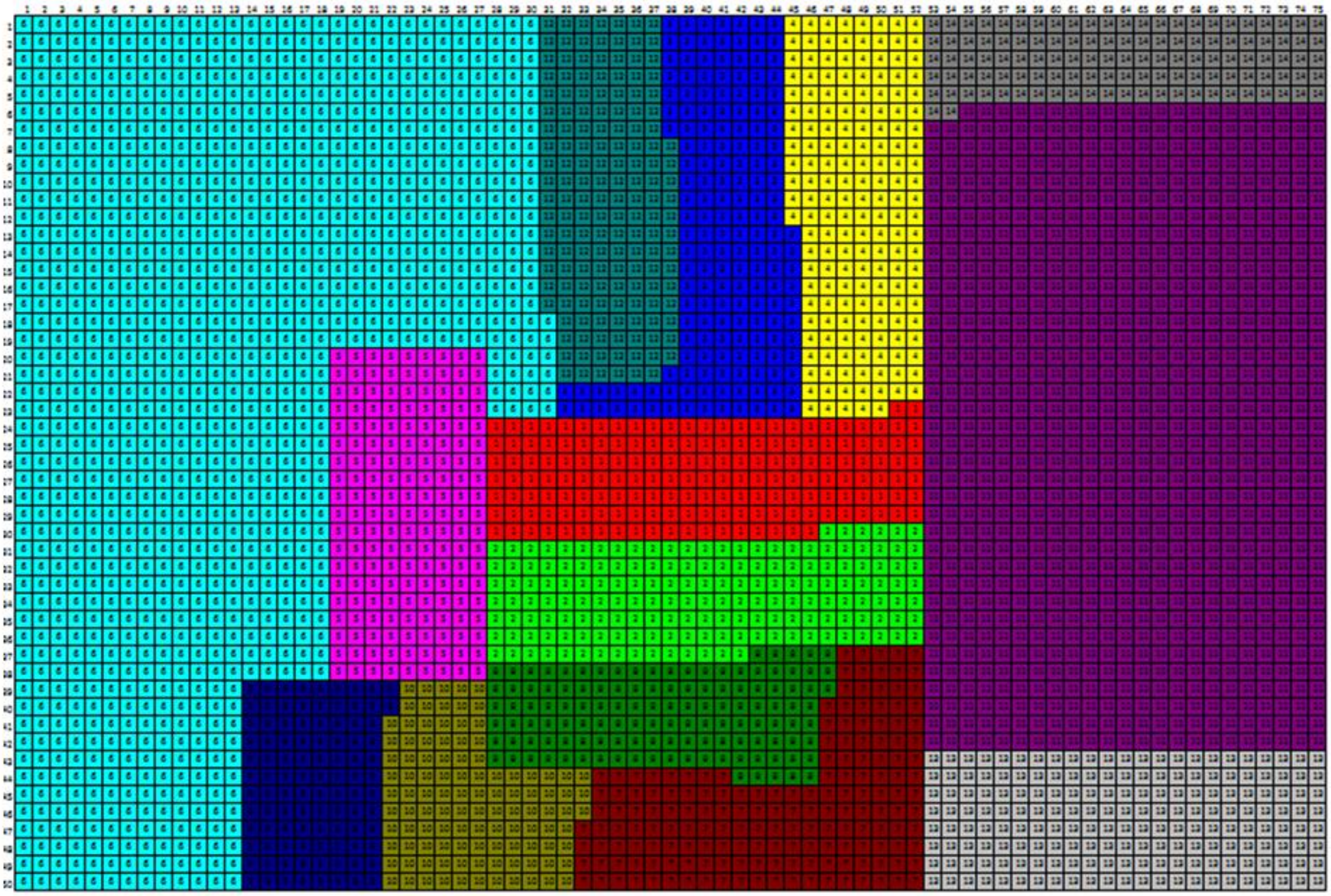
## Appendix C2

### Initial Layout for Craft Solution



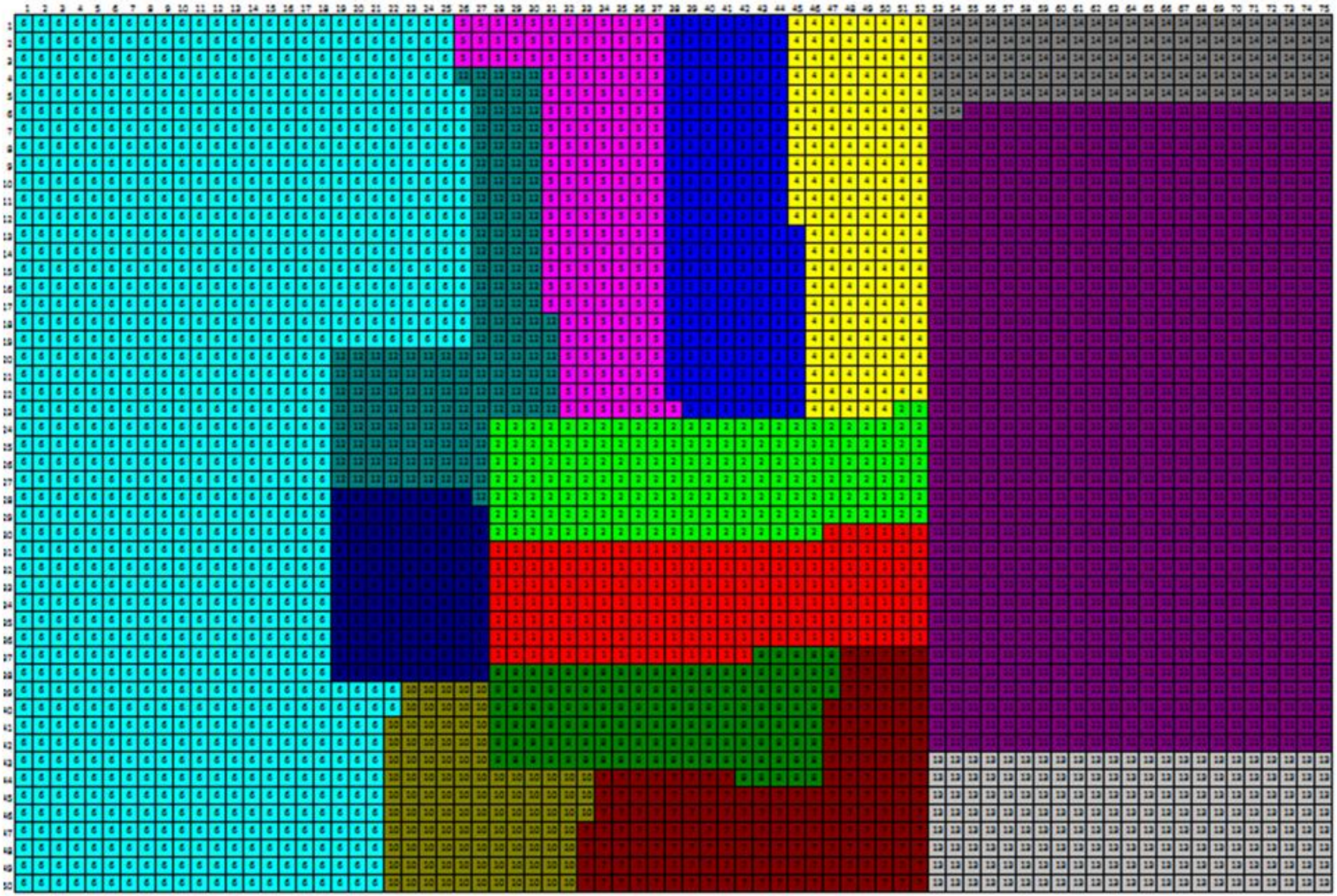
**Appendix C3**

**Craft Solution for Rectilinear Distance Measure**



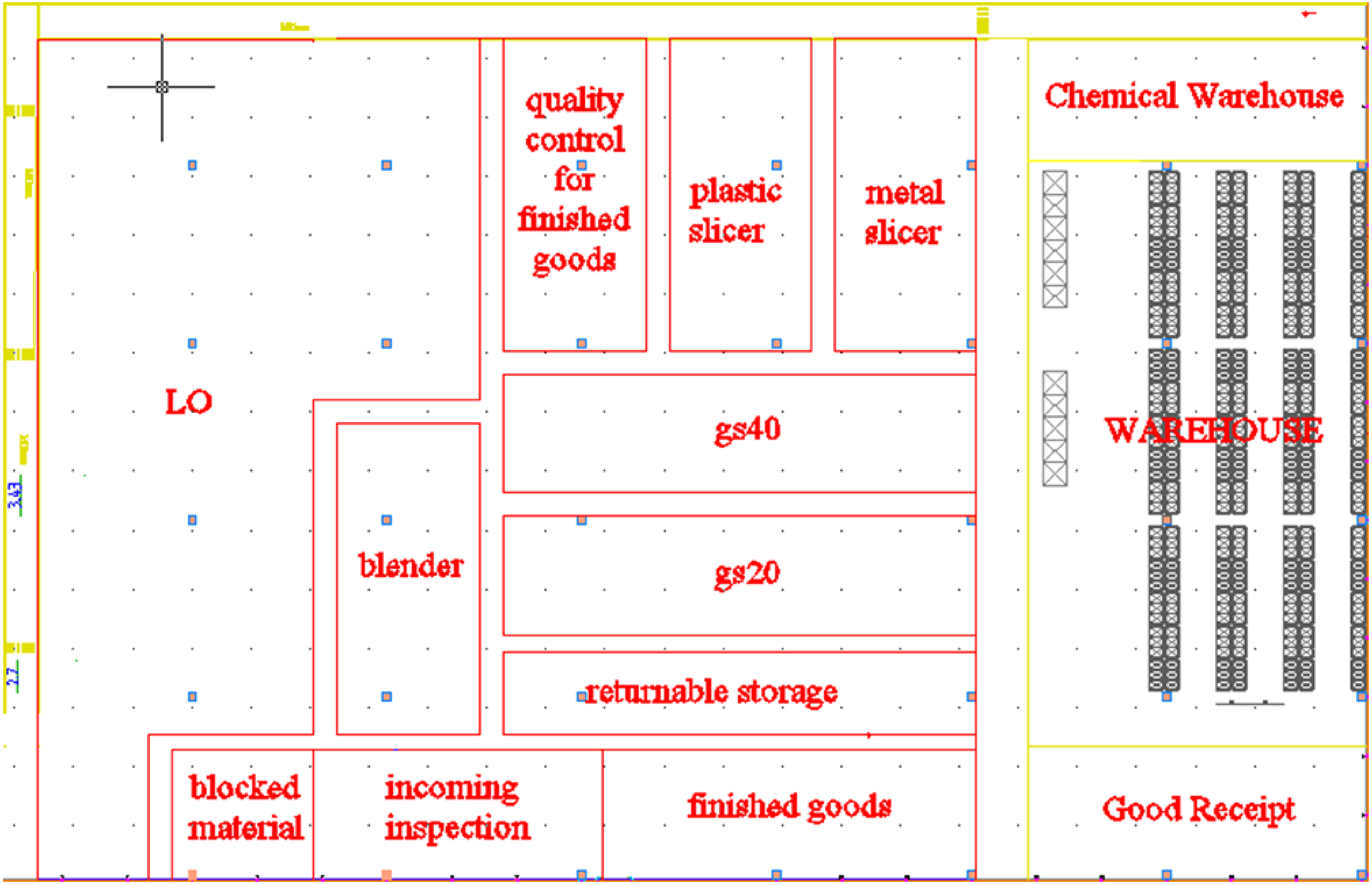
**Appendix C4**

**Craft Solution for Euclidean Distance Measure**



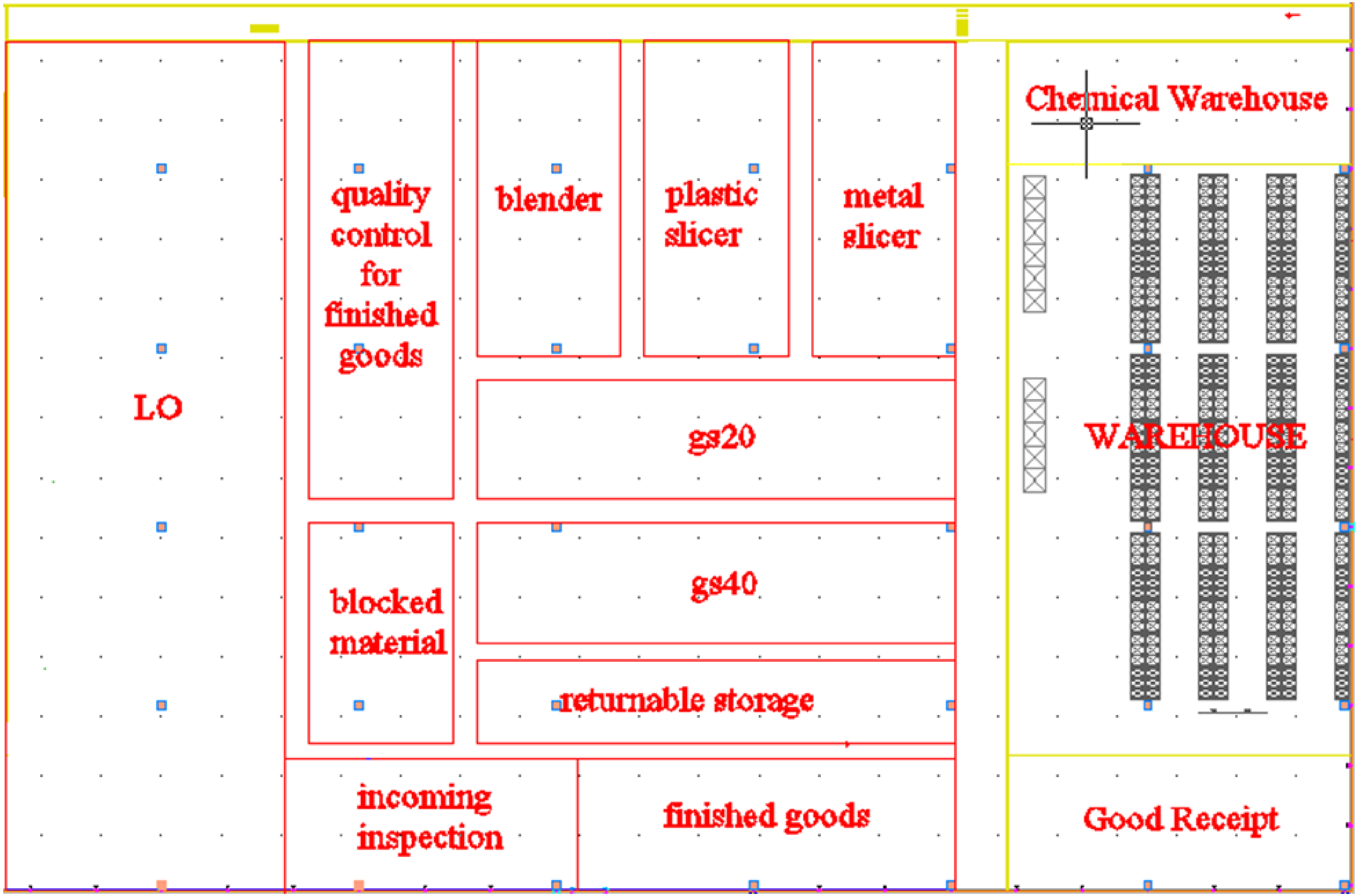
Appendix D1

**CAD DRAWING (Rectilinear Distance Measure)**



Appendix D2

CAD DRAWING (Euclidean Distance Measure)



## BIOGRAPHICAL SKETCH

Sevinç Koç was born in July 24, 1985 in Sivas. She graduated from Antalya Metin Nuran Çakallıklı Anatolian High School, in 2003 and from Departments of Management Engineering & Manufacturing Engineering, Istanbul Technical University in 2011. She started with her Master of Science study in the Institute of Science and Engineering, Galatasaray University in 2011.